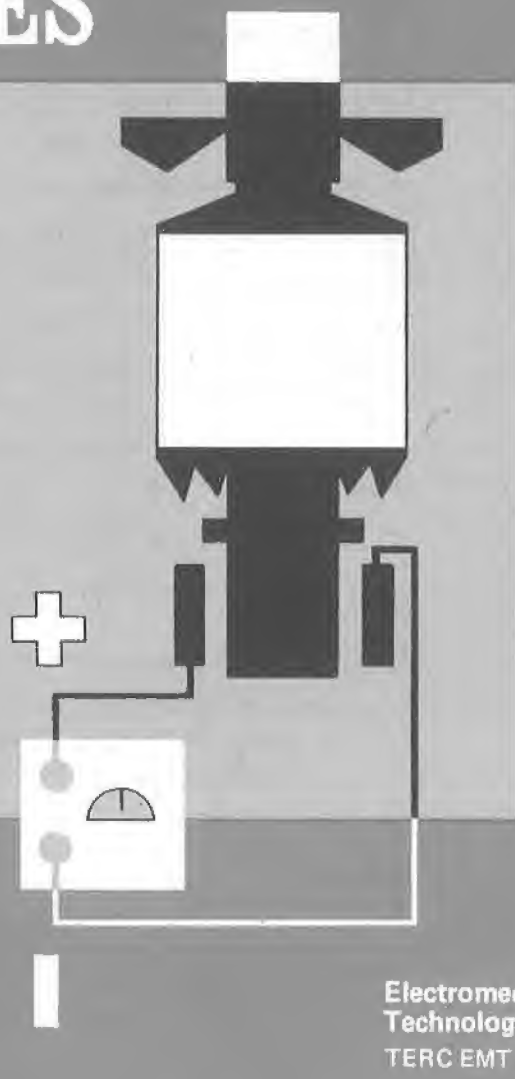
ELECTRO MECHANISMS

# DEVICES

INSTRUCTOR'S DATA GUIDE



Electromechanical Technology Series

TERC EMT STAFF

DELMAR PUBLISHERS, MOUNTAINVIEW AVENUE, ALBANY, NEW YORK 12205

**DELMAR PUBLISHERS**

Division of Litton Education Publishing, Inc.



Library of Congress Catalog Card Number:

72-162294

**PRINTED IN THE UNITED STATES OF AMERICA**

Published simultaneously in Canada by
Delmar Publishers, a division of
Van Nostrand Reinhold, Ltd.

The project presented or reported herein was performed pursuant to a grant from the U.S. Office of Education, Department of Health, Education, and Welfare. The opinions expressed herein, however, do not necessarily reflect the position or policy of the U.S. Office of Education, and no official endorsement by the U.S. Office of Education should be inferred.

# Preface

This *Instructor's Guide* is intended to make the electromechanical teacher's job a little easier. You will find that each experiment in *Electromechanisms/Devices* is covered in this guide.

The format is arranged to provide the instructor with useful, easy-to-find information about each laboratory experiment. The guide material for each experiment is arranged as follows:

**OBJECTIVE.** A brief statement of the main objectives of the experiment is given first. These objectives are frequently of an educational nature but are not stated in behavioral or performance goal terms.

**TECHNICAL TERMS.** Most of the technical terms are given in the instructor's guide for the experiment in which they first appear. A definition for each term is given in the guide. These definitions are of a practical nature rather than being rigorously exact. Instructors wishing more precise definitions may consult one of the excellent technical dictionaries currently available.

**MATHEMATICAL EXPRESSIONS.** The various equations, formulae, and expressions that appear in the experiment are listed.

**MATERIALS.** A complete list of the components and instruments required for each experiment is given in the guide. These lists are the same as those found in the student manual.

**DATA.** The data tables from the experiments are reproduced in the instructor's guide. The values shown in the tables were taken with the materials listed and as directed in the individual experiment. These values should be taken as *typical* only. Some variation from one data set to another is to be expected.

**PROBLEMS.** Solutions to the problems that are given in the student manual are shown in the guide. It should be noted that in some cases problem answers depend on the measured data. In such cases the answers given are *typical* only.

In addition to the information listed above, the guide often contains other comments in the form of precautions, analysis notes, or suggestions for enriching the student's experience.

Any set of instructional materials may be used to satisfy a wide variety of specific objectives depending upon the way they are used. Some of the objectives that are appropriate for a course using these exercises are listed below.

1. Given appropriate instruments, the student should be able to measure the angular velocity of a rotating component.
2. Given an electromechanical device from the types covered in the instructional materials, the student should be able to identify it by name.
3. Given an electromechanical device from the types covered in the course, the student should be able to write a brief description of its operation.
4. Given a circuit diagram from the instructional materials, the student should be able to select components and assemble the circuit.

5. Given an electromechanical device from the types covered in the course, the student should be able to list ways in which energy is stored, lost, or converted by the device.

These are but a few of the very many objectives which can be satisfied using these materials. The individual instructor is encouraged to establish his own objectives and use the materials in a way that satisfies them.

It is sincerely hoped that this instructor's guide will help to make the course in electromechanical devices more valuable to the student and more enjoyable for the instructor.

THE TERC EMT STAFF

# Contents

# *instructor's guide* 1 SOURCES OF INFORMATION

**INTRODUCTION.** This experiment is intended to introduce the student to the use of technical library materials.

## TECHNICAL TERMS

**Periodicals.** Magazines, newsletters or any other publication which is available on a periodic basis.

**Journals.** Periodicals that are published for special interest groups such as engineers, scientists or technicians.

**Theses.** Research papers written as part of the program leading to a Master's or Doctor's degree in a university.

**Indexes.** Systematic lists of publications by author, subject or source.

**Card File.** An index system using 3″ X 5″ cards employed by most libraries.

**Dewey Decimal System.** A method of cataloging books used by many libraries.

**Call Number.** The identification number assigned to a particular publication by a library.

## MATERIALS

Paper and pen

**DATA.** There is no numerical data in this exercise. The student is directed to follow these steps:

For each of the following, list the items below:

| | |
|---|---|
| *Call Number:* | For all books and, where applicable, for others. |
| *Author:* | For all books. |
| *Title:* | Complete title. |
| *Source:* | Publishing company for books and periodicals. |
| *Date:* | Copyright date of book or publication date of others. |
| *Coverage:* | Not over two sentences describing contents. |

1. A book on automobile solid-state ignition systems.
2. A book on automobile automatic transmissions.
3. An article out of *Popular Electronics* on stereo hi-fi systems.
4. An article out of *Popular Mechanics* on the road testing of a new anti-pollution fuel.
5. *Handbook of Chemistry and Physics*
6. A book of mathematics tables.
7. A machinist's handbook.
8. Three trade journals (periodicals specializing in electronics/mechanics).
9. An article on new discoveries in magnetism.
10. Assume you wish to purchase some small relays. List the names of three manufacturers that you would recommend to your purchasing department. Where did you find these?
11. You have a broken vacuum valve manufactured by Ultek. Whom would you call to discuss purchasing another? Where did you find his name and telephone number?

The student should be expected to submit written results in each of these areas as well as a paragraph explaining why practically all industrial concerns have a rather large technical library.

**PROBLEMS**

1. Tell what each of the following terms means.

   a) Index b) Card file c) Call number d) Periodicals

   Each of these terms is defined under Technical Terms, page 1.

2. What is the Dewey Decimal System?

   This term is defined under Technical Terms, page 1.

3. What kind of subjects are found in the 600 class in a library?

   The 600 class contains the "Useful Arts" materials. Engineering, Technology, and applied science are among the topics found there.

4. What is a trade journal?

   A trade journal is a periodical aimed at a specific occupational group. *Radio and TV News, The Journal of Technology,* and *The Journal of Applied Physics* are examples.

5. How many major classes of information would you expect to find in a library?

   There are 10 major classifications of information in the Dewey Decimal System. Each of these 10 major classes has 10 subgroups.

**INTRODUCTION.** The student should learn: characteristics of flux lines; the working of intensity, force and density problems; and magnetic terminology.

## TECHNICAL TERMS

**Magnet.** A material in which the magnetic domains are aligned and produce poles of north and south. In its natural form it is called a lodestone.

**Magnetism.** A property possessed by certain materials by which these materials can exert mechanical force on neighboring masses of magnetic materials.

**Ferromagnetic.** Materials that have a permeability many times greater than that of free space. The permeability of free space in the CGS system is 1.

**Electric Field.** The region immediately surrounding a charged body.

**Electrostatic.** Pertaining to static electricity, i.e., electricity, or an electric charge at rest.

**Poles.** The area where the flux lines enter or leave the magnet.

**Flux.** Invisible lines of force.

**Artificial Magnet.** Hardened steel which has been magnetized.

**Intensity of Magnetism (H).** Measured in Dynes/unit pole.

$$H = \frac{(f)}{(m)} \quad \begin{matrix} \text{force on a pole} \\ \text{strength in the pole} \end{matrix}$$

**Attracting or Repelling Force (f).** in Dynes.

$$f = \frac{m_1 m_2}{d^2}$$

$m_1$ = strength of pole 1 in unit poles
$m_2$ = strength of pole 2 in unit poles
$d$ = distance between poles in cm

**Magnetic Field.** The space around a magnet where the lines of force can be detected.

**Flux Density ($\beta$).** Number of magnetic lines of force per square centimeter perpendicular to the magnetic field.

**Electromotive Force (emf).** The force which causes electricity to flow when there is a difference of potential between two points. Its unit of measure is the volt.

**Magnetic Circuit.** A closed loop system in which the *flux* is analogous to *current* and *magnetomotive force* is analogous to *electromotive force.*

**Magnetomotive Force.** The force by which a magnetic field is produced, either by a current flowing through a coil of wire, or by the proximity of a magnetized body.

**Reluctance (R).** The opposition of a material to the passage of magnetic flux. *Reluctance* is analogous to *resistance* in the electric circuit.

**Reluctivity (V).** The specific reluctance or the reluctance per cubic centimeter. *Reluctivity* corresponds to the *resistivity* of an electric material.

**Permeance (P).** The ability of a material to permit the setting up of magnetic lines of force. *Permeance* is analogous to *conductance* in the electric circuit.

**Permeability (m).** The specific permeance or the permeance per cubic centimeter. *Permeability* corresponds to the *conductivity* of an electric circuit.

**Retentivity.** The ability of a material to retain magnetism after the magnetizing force has been removed.

**Remanence.** Also called the residual magnetism. The greatest number of flux lines a material can maintain per cubic centimeter after the magnetizing force has been removed.

**Coercive Force.** The demagnetizing force required to reduce the residual magnetism to zero.

**Diamagnetic Materials.** Those materials which have a permeability less than free space. They become very weakly magnetized in a direction opposite to that of the magnetizing field.

**Paramagnetic Materials.** Those materials that have a permeability that is slightly greater than 1. These materials become weakly magnetized in the same direction of the magnetizing field.

**Curie Temperature.** The temperature above which a ferromagnetic material becomes substantially non-magnetic.

**Magnetic Shielding.** Providing an easy path for magnetic lines for shielding.

## MATHEMATICAL EXPRESSIONS

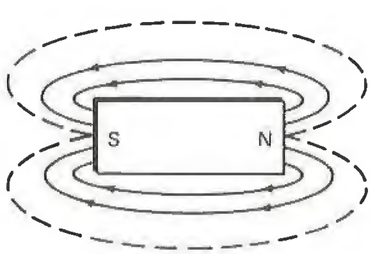
$$f = \frac{m_1 m_2}{d^2} \qquad \beta = \frac{\phi}{A}$$

## MATERIALS

2 Bar magnets
1 Compass
1 Ruler in inches and centimeters
Iron filings in a pepper shaker

## DATA

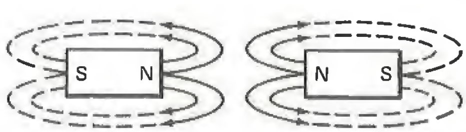
| Configuration | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Distance in Centimeters | 1.5 | 1 | 2.3 | 1.6 | 1.4 |




A. MAGNETIC PATTERN OF SINGLE BAR

A. This magnetic pattern shows these characteristics:

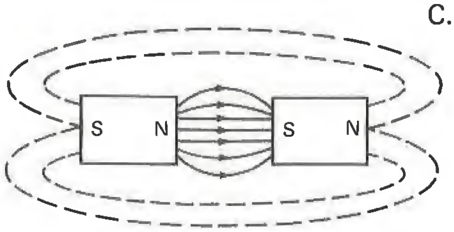
1. Magnetic lines of force possess direction.
2. Magnetic lines of force always form complete loops.
3. Magnetic lines of force cannot intersect.
4. The magnetic field is most intense where the lines are the closest together.




B. MAGNETIC PATTERN OF OPPOSING FIELDS

B. This magnetic pattern shows these characteristics:

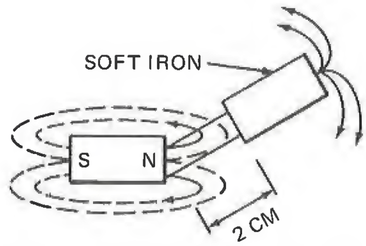
1. Magnetic lines of force possess direction.
2. Magnetic lines of force always form complete loops.
3. Magnetic lines of force cannot intersect.
4. The magnetic field is most intense where the lines are closest.
5. Lines acting in the opposite direction tend to repel each other.




C. MAGNETIC PATTERN OF ATTRACTING FIELDS

C. This magnetic pattern shows these characteristics:

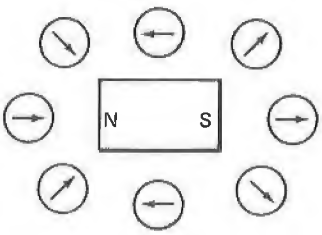
1. Magnetic lines of force possess direction.
2. Magnetic lines of force always form complete loops.
3. Magnetic lines of force represent a tension along their length which tends to make them as short as possible.
4. Magnetic lines of force cannot intersect.
5. Lines acting in the same direction tend to attract each other.
6. The magnetic field is most intense where the lines are closest together.



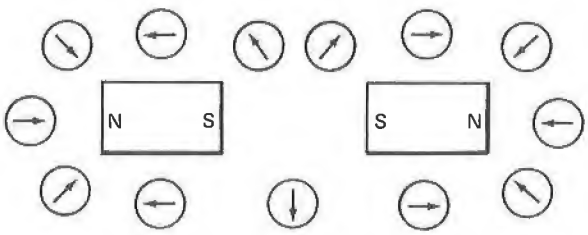

D. MAGNETIC PATTERN OF LINES TAKING PATH OF LEAST OPPOSITION

D. This magnetic pattern shows these characteristics.

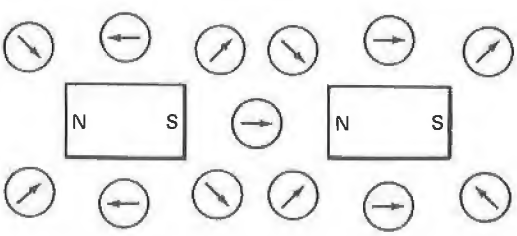
1. Magnetic lines of force possess direction.
2. Magnetic lines of force always form complete loops.
3. Magnetic lines of force follow the path of least opposition.
4. Magnetic lines of force represent a tension along their length which tends to make them as short as possible.




CHARTING THE DIRECTION OF TRAVEL OF MAGNETIC LINES OF FORCE




DIRECTION OF MAGNETIC LINES OF FORCE WITH OPPOSING FIELDS




DIRECTION OF MAGNETIC LINES OF FORCE WITH ATTRACTING FIELDS

## PROBLEMS

1. A 10-lb. magnet with a north pole strength of 100 unit poles is placed 5 cm from a south pole of a magnet weighing 5 lbs. whose strength is 500 unit poles. What is the force in pounds acting on these poles?

$$f = \frac{m_1 m_2}{d^2} = \frac{(100)500}{25} = 2000 \text{ dynes}$$

$$2000 \text{ dynes} \times \frac{1 \text{ gram}}{981 \text{ dynes}} \times \frac{1 \text{ lb}}{454 \text{ grams}} = f_{(\text{lbs})} = \mathbf{4.49 \times 10^{-3} \text{ lbs}}$$

2. The north magnetic pole of a permanent magnet has a total flux of 250,000 lines. If the field is uniformly distributed and the pole is 2 cm wide and 5 cm long, what is the flux density?

$$\beta = \frac{\phi}{A} \qquad \phi = 250{,}000 \text{ lines} = 250{,}000 \text{ Maxwells}$$

$$\beta = \frac{250{,}000 \text{ Maxwells}}{10 \text{ in}^2} = \mathbf{25{,}000 \text{ Gausses}}$$

3. What is the Curie temperature of iron, nickel, and cobalt?

   Curie temperature of: Iron = 770°C; Nickel = 358°C; Cobalt = 1,131°C.

4. Would a speaker with the heaviest magnet definitely have a stronger magnetic field? Why?

   The weight of a magnet does *not* indicate its flux density.

5. If $6 \times 10^{-6}$ Webers pass through an area of 1.2 square meters, find (a) the flux in Maxwells and in lines, (b) find the flux density in Webers/square meter, in Gausses, and in lines/sq. in.

a) $\phi = 6 \times 10^{-6}$ Webers

$$6 \times 10^{-6} \text{ Webers} \times \frac{1 \text{ Maxwell}}{10^{-8} \text{ Webers}} = \mathbf{600 \text{ Maxwells}}$$

$$600 \text{ Maxwells} \times \frac{1 \text{ line}}{1 \text{ Maxwell}} = \mathbf{600 \text{ lines}}$$

b) $$\beta = \frac{\phi}{A} = \frac{6 \times 10^{-6} \text{ Webers}}{1.2 \text{ meters}^2} = 5 \times 10^{-6} \text{ Webers/meter}^2$$

$$5 \times 10^{-6} \text{ Webers/meter}^2 \times \frac{6.452 \text{ lines/in}^2}{10^{-4} \text{ Webers/meter}^2} = \mathbf{.3225 \text{ lines/in}^2}$$

$$5 \times 10^{-6} \text{ Webers/meters}^2 \times \frac{1 \text{ Gauss}}{10^{-4} \text{ Webers/meter}^2} = \mathbf{5.04 \times 10^{-2} \text{ Gausses.}}$$

6. If you have two identical pieces of iron and one is permanently magnetized and the other is not, how can you determine which of the two is the magnet? Explain.

   By tying a string around the magnetized piece of iron and allowing it to hang in the air. It will be attracted by the earth's magnetic poles and align itself to them. The unmagnetized piece of iron will not be affected by the earth's magnetic poles.

# 3 ANGULAR VELOCITY MEASUREMENTS

**INTRODUCTION.** The student should understand: The types of revolution-per-minute counters; their principles of operation and measurement techniques.

## TECHNICAL TERMS

**Tachometer.** An instrument used to measure the frequency of mechanical systems by the determination of angular velocity.

**Stroboscope.** A device which indicates frequency of operation by creating the optical illusion of slowing down or stopping a moving pattern. It is illuminated by a light that flashes at a known frequency.

**Centrifugal Force.** The force which acts on a rotating body and which tends to throw the body farther from the axis of its rotation.

**Mass.** The quantity of matter in an object. It is equal to the weight of a body divided by the acceleration due to gravity.

**Transducer.** A device in which the magnitude of an applied force is converted into an electrical signal proportionate to the quantity of the force.

**Generator.** A rotating machine which converts mechanical energy into electrical energy.

**Saturable Transformer.** Also a saturable reactor or a magnetic core reactor, the opposition of which is controlled by changing the saturation of the core.

**Capacitor.** Two conductors separated by a dielectric which stores the potential difference between the conductors.

**Frequency.** The number of recurrences of periodic phenómenon in a unit of time.

**Laminated.** Made of layers.

**Rectification.** The conversion of alternating current into unidirectional or direct current.

## MATHEMATICAL EXPRESSIONS

$$n = \frac{\omega}{F}$$

$$\omega = \frac{f_2 f_1}{f_2 - f_1}$$

## MATERIALS

1 DC series motor—28 volt, 7000 RPM (max.)
1 Variable DC power supply
1 Mechanical tachometer, 0–1000 RPM (max.)
1 Stroboscope
1 Mounting board

## DATA

| TIME | REVOLUTIONS PER MINUTE (RPM) | | | |
|---|---|---|---|---|
| 0 | 0 | 1700 | 3800 | 4900 |
| 15 sec. | 0 | 1800 | 4000 | 4900 |
| 30 sec. | 0 | 1850 | 4050 | 4900 |
| 45 sec. | 0 | 1850 | 4050 | 4900 |
| 1 min. | 0 | 1850 | 4050 | 4900 |
| Average RPM | 0 | 1810 | 3990 | 4900 |
| Volts | 5 | 10 | 15 | 20 |

*Fig. 3-12 Volts - RPM Data Table for Mechanical Tachometer*

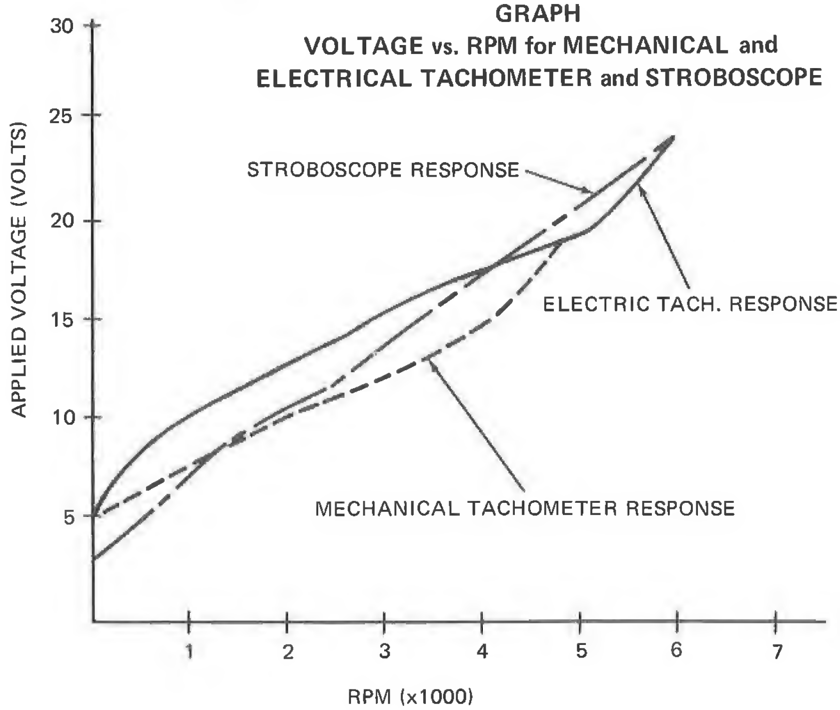
GENERATOR VOLTAGE/RPM 3.8V/100 RPM

| | | | | | |
|---|---|---|---|---|---|
| Motor Voltage | 5 | 10 | 15 | 20 | 25 |
| Generator Output (Volts) | 0 | 31.2V | 105V | 194V | 232V |
| Motor RPM | 0 | 820 | 2760 | 5100 | 6100 |

*Fig. 3-14 Volts - RPM Data Table for DC Generator Tachometer*

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Readings | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Volts | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 |
| RPM | 0 | 660 | 1.35k | 2.4k | 3.3k | 4.1k | 5k | 5.9k | 6.8k | 7.6k |

*Fig. 3-15 Volts - RPM Data Table for Stroboscope*




**ANALYSIS.** The graph shows the response of the mechanical and electrical tachometers and the stroboscope. The mechanical and electrical tachometer response curves show the loading applied by the measuring devices. The stroboscope response is nearly linear, since no load was applied.

The generated voltage per RPM for each generator can be determined by running the generator at some speed that can be found with a stroboscope and recording the output voltage at that speed.

**PROBLEMS**

1. If a revolution counter records 1500 revolutions in 20 seconds, determine the RPM.

$$\frac{1500 \text{ rev}}{20 \text{ sec}} \times \frac{60 \text{ sec}}{1 \text{ min}} = \frac{90000 \text{ rev}}{20 \text{ min}} = \mathbf{4500\ RPM}$$

2. A motor turns 1725 RPM. How many revolutions does it turn per second, per hour?

$$1725 \text{ rev/min} \times 1 \text{ min/60 sec} = \frac{1725 \text{ rev}}{60 \text{ sec}} = \mathbf{28.75\ rev/sec}$$

$$1725 \text{ rev/min} \times 60 \text{ min/hr} = \mathbf{103{,}500\ rev/hr}$$

3. The volts per RPM in an electrical tachometer is 0.05 volts. What is the RPM if the voltage is increased to 30?

$$\frac{.05 \text{ volts}}{30 \text{ volts}} = \frac{1 \text{ RPM}}{X} \qquad X = \frac{30 \text{ volts } (1\text{RPM})}{.05 \text{ volts}} = \mathbf{600\ RPM}$$

4. If the flash rate of a strobe light is 2000 fpm and the shaft speed of a motor is 6000 RPM, what is the revolutions per flash?

$$n = \frac{\omega}{F} = \frac{6000}{2000} = \textbf{3 revolutions per flash}$$

5. What is the true shaft speed of a motor if the lower flash point is 1500 and the upper flash point is 2000?

$$\omega = \frac{f_2 f_1}{f_2 - f_1} = \frac{(2000)\ (1500)}{2000 - 1500} = \textbf{6000 RPM true shaft speed}$$

## *instructor's guide* 4 *MOTOR LOADING-NO LOAD TEST*

**INTRODUCTION.** The student should learn how simple AC and DC motors are constructed and how power losses and efficiency affect their operation.

### TECHNICAL TERMS

**Opposition.** Resistance. To restrict or limit energy transfer.

**Friction.** The opposition offered when one surface is moved across another.

**Electrons.** One of the natural, elementary constituents of matter. It carries a negative electric charge of one electronic unit and has approximately 1/1840th the mass of a hydrogen atom or $9.107 \times 10^{-28}$ gm.

**Valve.** A mechanical device by which the flow of a liquid, gas, or loose material in bulk can be stopped, restricted, or regulated.

**Power Loss.** The ratio of input power to output power.

**Rotor.** The rotating member of an electrical device.

**Stator.** The non-rotating part of the magnetic structure in an induction motor. It usually contains the primary winding.

**Housing.** The portion of a motor or generator which encloses the internal parts.

**Torque.** The product of the force and its perpendicular distance from the axis of its rotation to its line of action.

**Watt.** A unit of the electric power required to do work at the rate of one joule per second. It is the power expended when one ampere of direct current flows through a resistance of one ohm.

**Ohm's Law.** The voltage across an element of a DC circuit is equal to the current in amperes through the element, multiplied by the resistance of the element in ohms.

**Windage.** Mechanical losses due to bearing friction, wind resistance against rotor, etc.

**Hysteresis.** The difference between the response of a unit or a system to an increasing and a decreasing signal.

**Eddy Currents.** Those currents induced in the body of a conducting mass by a variation in magnetic flux. This action is reduced when the body of the conducting mass is made of a laminated material.

**Magnetic Flux Density.** The total amount of magnetic flux per unit area.

**Counter electromotive force (Cemf).** A voltage developed in an inductive circuit by an alternating or pulsating current. The polarity of this voltage is at every instant opposite that of the applied voltage.

**No-Load Test.** A circuit test with no load attached to the output, so losses in power of the stator, core and windage can be computed.

**Load Test.** A motor test with attached load to find power losses.

**Generator.** A rotating machine which converts mechanical energy into electrical energy.

### MATHEMATICAL EXPRESSIONS

$$T = K\phi_p I_a$$

$$T = Fr$$

$$\%\ \text{regulation} = \frac{\omega_{NL} - \omega_{FL}}{\omega_{FL}} \times 100$$

$$P = \frac{W}{t}$$

$$P = F\omega r 2\pi$$

$$T = \frac{5250\ HP}{\omega}$$

$$P = E \times I = \frac{E^2}{R_a} = I^2R$$

$$Cemf = \frac{2\phi C\omega}{10^8} = K\phi\omega$$

$$P = I_a{}^2R_a = \frac{(E - Cemf)^2}{R_a} \text{ or } (E - Cemf)\ I_a$$

$$K = \frac{PZ}{2\pi a}$$

$$W = Fd$$

$$HP = 33{,}000 \text{ ft-lbs/min} = 550 \text{ ft-lbs/sec}$$

$$P = E \times I$$

$$\%\ Eff = \frac{.142\ T\omega}{I_a{}^2R_a}$$

$$I_a = \frac{E - Cemf}{R_a} = \frac{E - K\phi\omega}{R_a}$$

## MATERIALS

2 DC motors, 28 volt, 0.7 amp, 7000 RPM
1 DC power supply
2 VOM meters
1 Stroboscope
1 Motor shaft coupling
1 Test board

## DATA

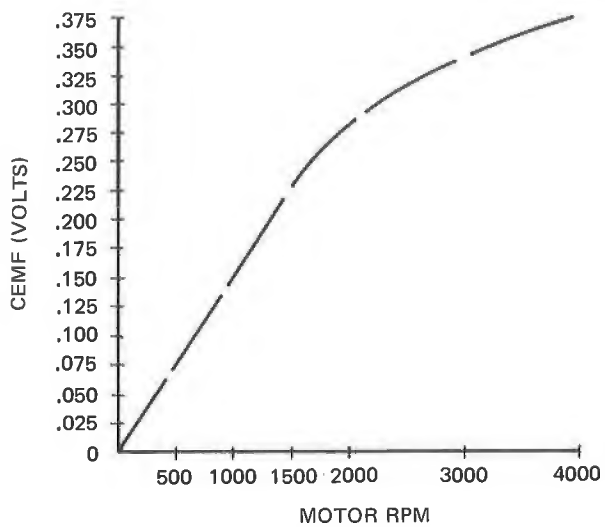
| RPM | Cemf (volt. output) |
|---|---|
| 0 | 0 |
| 500 | .067 |
| 1000 | .14 |
| 1500 | .22 |
| 2000 | .285 |
| 3000 | .335 |
| 4000 | .375 |

*Fig. 4-11 Cemf of Motor versus RPM*

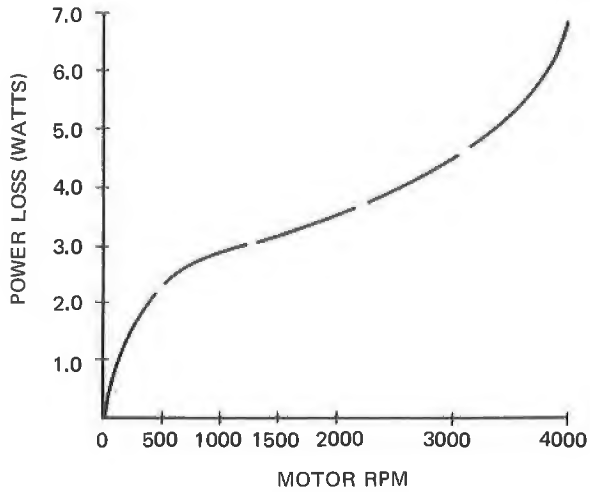
| From Experiment | | | Compute | Compute Power Loss |
|---|---|---|---|---|
| RPM | $E_a$ | $I_a$ | $E_a$ – Cemf | $P = (E_a - Cemf)\ I_a$ |
| 0 | 0 | 0 | 0 | 0 |
| 500 | 7.7V | .317A | 7.633 | 2.42W |
| 1000 | 9.5 | .305 | 9.36 | 2.85 |
| 1500 | 10.5 | .31 | 10.28 | 3.18 |
| 2000 | 12 | .30 | 11.715 | 3.52 |
| 3000 | 15.5 | .295 | 15.165 | 4.46 |
| 4000 | 20.5 | .34 | 20.125 | 6.84 |

*Fig. 4-12 Power Loss versus RPM*

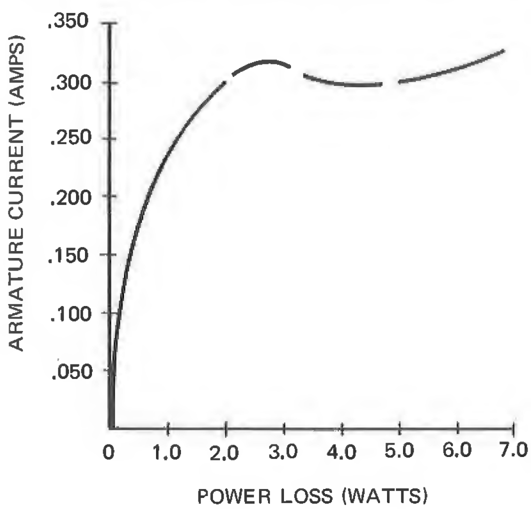
GRAPH 1 CEMF VS. RPM




GRAPH 2 POWER LOSS VS. MOTOR RPM




GRAPH 3 ARMATURE CURRENT VS. POWER LOSS




**ANALYSIS.** Graph 1 shows that the counter electromotive force developed in a motor increases in a linear manner until saturation at approximately 1500 RPM.

The curve drawn in Graph 2 shows that as motor RPM increases, the power loss increases until maximum motor RPM is obtained. The power losses will increase from this point on but motor RPM will remain constant.

Graph 3 shows that a small change in the armature current is associated with a large change in motor power loss.

During the operation of the experiment, caution should be used when running the motor at 3000 to 4000 RPM. The 7000 RPM rating for maximum speed is with a very small load and therefore not obtainable when measuring counter emf.

The best range of speed for this motor to be used is from 0–2000 RPM. Graph 1 shows that the counter emf is constant at this range and Graph 2 shows that the power losses are approximately constant to 2000 RPM also.

**PROBLEMS**

1. What is the percent efficiency of a one-half HP motor that uses 500 watts from the power source?

$$P_{in} = 500 \text{ watts}$$

$$P_{out} = 1/2 \text{ HP} = 1/2 \ \frac{746 \text{ watts}}{1 \text{ HP}} = 373 \text{ watts}$$

$$\% \text{ Eff} = \frac{P_{out}}{P_{in}} \times 100 = \frac{373 \text{ watts}}{500 \text{ watts}} \times 100 = \mathbf{74.5\%}$$

2. What is the percent efficiency of a five horsepower DC motor if it has the following losses: 525 watts in the iron core; 50 watts in the field copper; 175 watts in the armature copper; and 210 watts in windage and friction?

$$P_{in} = P_{out} + \text{Power losses} = 3730 \text{ watts} + 960 \text{ watts} = 4690 \text{ watts}$$

$$P_{out} = 5 \text{ HP} = 5 \text{ HP} \times \frac{746 \text{ watts}}{1 \text{ HP}} = 3730 \text{ watts}$$

$$\% \text{ Eff} = \frac{P_{out}}{P_{in}} \times 100 = \frac{3730 \text{ watts}}{4690 \text{ watts}} \times 100 = \mathbf{79.6\%}$$

3. What is the rated full-load torque of a two-horsepower, 2000 RPM motor?

$$T = \frac{5250 \text{ HP}}{\omega} = \frac{5250 \text{ (2HP)}}{2000 \text{ RPM}} = \mathbf{5.25 \ lb\text{-}ft}$$

4. What is the horsepower rating of a motor that delivers 4.2 oz-in. of torque at 3000 RPM?

$$\text{HP} = \frac{\omega T}{5250} = \frac{(3000 \text{ RPM})\ T}{5250}$$

$$T_{lb\text{-}ft} = 4.2 \text{ oz-in.} \times \frac{1 \text{ lb}}{16 \text{ oz}} \times \frac{1 \text{ ft}}{12 \text{ in.}} = .262 \text{ lb-in.} \times \frac{1 \text{ ft}}{12 \text{ in.}} = .0219 \text{ lb-ft}$$

$$\text{HP} = \frac{3000 \text{ RPM } (.0219 \text{ lb-ft})}{5250} = \mathbf{0.0125 \ HP \ rating}$$

**INTRODUCTION.** The student should learn the different types of motors and how the speed, torque, and construction differ for each type.

## TECHNICAL TERMS

**Series Wound.** A commutator motor in which the field and armature circuits are in series.

**Shunt Wound.** A direct current motor in which the field circuit and armature circuit are connected in parallel.

**Compound Wound.** A DC motor having two separate field windings. One, usually the predominant field, is connected in parallel with the armature circuit and the other is connected in series.

**Excited (Excitation current).** The resultant current in the shunt field of a motor when voltage is applied across the field.

**Torque.** In a force, the product of the force and its perpendicular distance from the axis of its rotation to its line of action.

**Carbon Brush.** A current-carrying brush made of carbon, carbon and graphite, or carbon and copper.

**Commutator.** The part of the armature to which the coils of a motor are connected. It consists of wedge-shaped copper segments arranged around a steel hub and insulated from it and from one another. The motor brushes ride on the outer edges of the commutator bars and thereby connect the armature coils to the power source.

**Speed Regulation.** The speed change of a motor between full-load and no-load, expressed in percent of full-load speed.

**Centrifugal Governor.** A motor attachment that automatically controls the speed at which the motor rotates.

**Saturation.** The state of magnetism beyond which a metal or alloy is incapable of further magnetization.

**Cumulative Compounded.** When the shunt and the series field windings produce the same magnetic polarity at the poles of the motor.

**Differential Compounded.** When the shunt and the series field windings produce opposite voltage.

**Long Shunt.** When the shunt receives full input voltage.

**Short Shunt.** When the shunt is placed only across the armature.

**Polyphase.** Having or utilizing several phases. Thus, a polyphase motor operates from a power line having several phases of alternating current.

**Single Phase.** A circuit in which all voltages are in phase or 180° out of phase.

**Horsepower.** A unit of power, or the capacity of a mechanism to do work in a period of time.

**Watt.** A unit of the electric power required to do work at the rate of 1 joule per second.

**Prony Brake.** Equipment that measures the power output of a rotating machine by determining the friction absorbed by a handbrake as it opposes the rotation of the machine.

**Brake Horsepower.** The computed horsepower of a device when using the formula

$$P = \frac{2\pi Fr \times RPM}{33{,}000} \text{ HP}$$

**Friction.** The opposition offered between two moving bodies in contact with each other.

**Power Loss.** The difference between the input power of a system or device and the usable output power.

## MATHEMATICAL EXPRESSIONS

$$T = K\phi_p I_a$$

$$W = Fd$$

$$HP = \frac{\text{ft-lbs in one second}}{550}$$

$$P = \frac{T\omega}{5250} \text{ HP}$$

$$\% \text{ efficiency} = \frac{\text{output}}{\text{input}} \times 100$$

$$T = Fr$$

$$HP = \frac{\text{ft-lbs in one minute}}{33{,}000}$$

$$W = I \times E$$

$$P_L = \frac{(E - Cemf)I_a}{746} - \frac{F2\pi r(\omega)}{33{,}000}$$

## MATERIALS

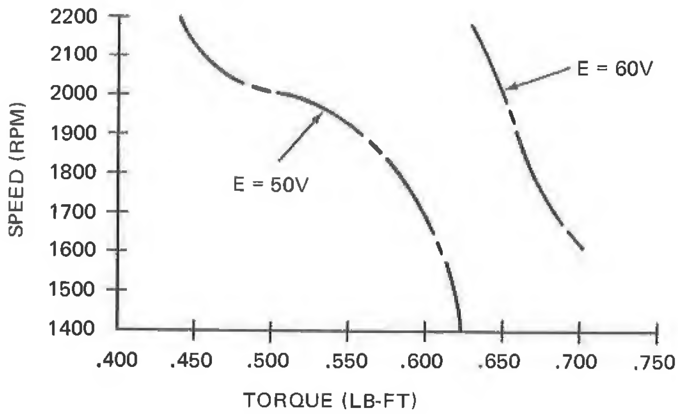
1 Dynamometer
1 Universal or DC motor
1 DC power supply with voltage and current meters
Appropriate couplings and motor mounts as needed
5 Sheets graph paper, 10 X 10 division/inch

## DATA

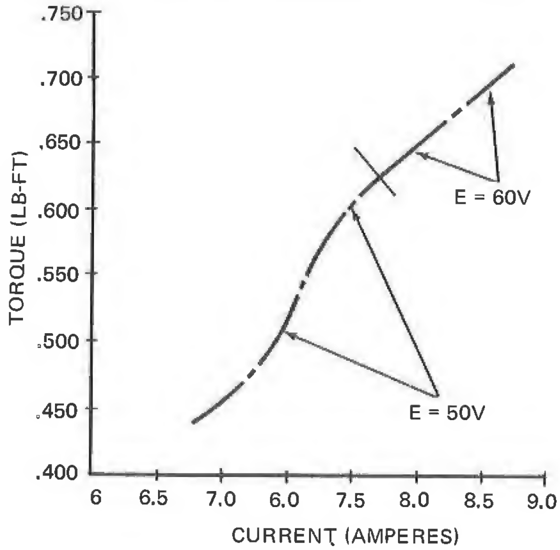
| Voltage | Force oz | Torque in.–oz | Speed RPM | Current A | $P_{in} = I^2R$ W | $P_o = \frac{T\omega}{5250}$ HP | $P_o$ in Watts | Efficiency % |
|---|---|---|---|---|---|---|---|---|
| 50 | 21 | .438 | 2200 | 6.8 | 163 | .183 | 136 | 83.4 |
| 50 | 24 | .50 | 2000 | 7.4 | 193 | .19 | 142 | 73.6 |
| 50 | 28 | .583 | 1800 | 7.6 | 204 | .20 | 149 | 73.0 |
| 50 | 29 | .605 | 1600 | 8 | 226 | .184 | 137 | 60.8 |
| 50 | 30 | .626 | 1400 | 8.2 | 237 | .167 | 125 | 52.8 |
| 60 | 30 | .626 | 2200 | 8.2 | 238 | .262 | 195 | 81.7 |
| 60 | 31 | .646 | 2000 | 8.4 | 248 | .246 | 183 | 73.8 |
| 60 | 32 | .667 | 1800 | 8.8 | 273 | .228 | 170 | 62.4 |
| 60 | 34 | .708 | 1600 | 9.2 | 300 | .216 | 161 | 53.8 |

*Fig. 5-10*

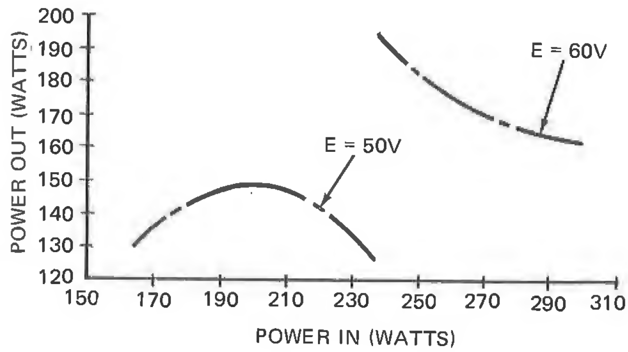
GRAPH 1 TORQUE VS. SPEED



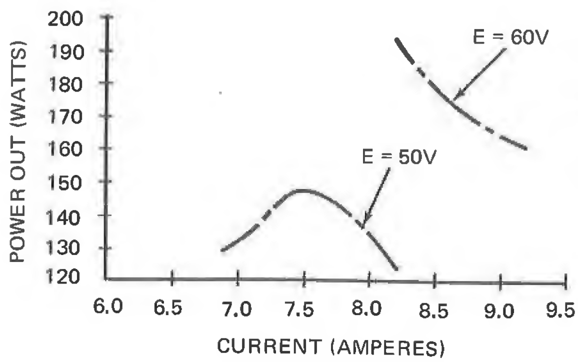

GRAPH 2 CURRENT VS. TORQUE



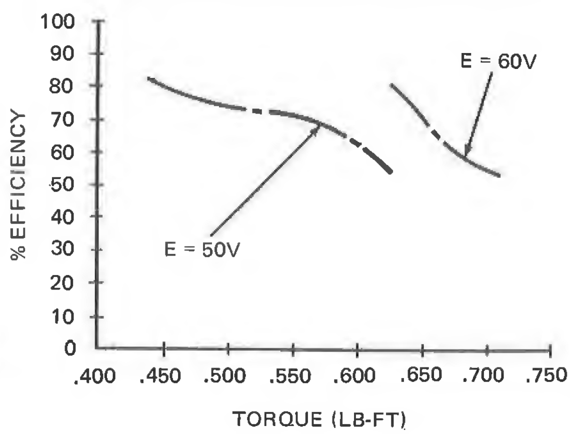

GRAPH 3 POWER IN VS. POWER OUT




GRAPH 4 CURRENT VS. POWER OUT




GRAPH 5 TORQUE VS. % EFFICIENCY



**ANALYSIS.** Graph 1 shows that decrease in speed of a motor will cause an increase in torque of the motor. Graph 2 shows that the torque increases linearly as the current increases. Graph 3 shows as the power in increases the power out decreases. When the applied voltage was 50 volts, the power out increased until a maximum and then decreased. The highest point on this curve is the maximum output power of the motor at 50 volts. Graph 4 displays approximately the same curves as Graph 3 since the power in is directly proportional to current. Graph 5 shows that the percent efficiency of power out to power in decreases as the torque of the motor increases.

## PROBLEMS

1. What ratio does the efficiency of a motor represent? How does the efficiency of a motor affect its operating cost?

   The efficiency of a motor represents the ratio of usable output power to input power. The higher the efficiency of a system, the less the cost of operation.

2. How much torque is delivered by a 1/50 HP, 4000 RPM motor? How much force is developed at the surface of the rotating member if its diameter is 1-1/2 inches?

$$T = \frac{5250\ (\text{HP})}{\omega} = \frac{5250\ (1/50\ \text{HP})}{4{,}000\ \text{RPM}} = .0263\ \text{lb-ft}$$

$$F = \frac{T}{r} = \frac{.0263\ \text{lb-ft}}{3/4''} = \frac{.3156\ \text{lb-in.}}{.75\ \text{in.}} = \mathbf{.450\ lbs}$$

3. What is the efficiency of a 1/45 HP, 1600 RPM motor that takes 23.4 watts from the power source?

   1/45 HP = 16.41 watts

$$\%\ \text{eff.} = \frac{P_o}{P_{in}} = \frac{23.4\ \text{watts}}{16.41\ \text{watts}} \times 100 = \mathbf{70\%}$$

**INTRODUCTION.** The student should learn the relationships between the primary and secondary windings of a transformer, the different types of transformers and how losses affect their operation.

## TECHNICAL TERMS

**Transformer.** An electrical device which, by electromagnetic induction, transforms electrical energy from one circuit to another at the same frequency, but usually at a different voltage and current value.

**Hydroelectric Station.** A unit which produces electricity by water power.

**Electromagnetic Induction.** The voltage produced in a coil as the number of magnetic lines of force passing through the coil changes.

**Magnetic Field.** An area where magnetic forces can be detected around a permanent, natural, or electromagnet.

**Primary Winding.** The transformer winding that receives electrical energy from a source and sets up proportional electrical energy in the secondary winding.

**Secondary.** The transformer output winding where the electrical energy flow is due to the inductive coupling with the primary.

**Mutual Induction.** The production of a voltage in one circuit by a changing current in a neighboring circuit, even though no connection exists between the two circuits.

**Link (link coupling).** Inductive coupling between circuits.

**Impedance.** The total opposition (resistance and reactance) of a circuit to the flow of alternating current, measured in ohms.

**Reflected Impedance.** The apparent impedance across the primary of a transformer when current flows in the secondary.

**Impedance Matching.** A transformer used to match the impedance of a source and load to transfer maximum energy.

**Core Type.** A transformer in which the windings are placed on the outside of the core so the material can intensify the magnetic field.

**Shell-type Transformer.** A transformer in which the magnetic circuit completely surrounds the windings.

**Efficiency.** The ratio of the useful output energy to the total amount of input energy.

**Air Core Transformer.** A transformer having two or more coils wound around a nonmetallic core.

**Reluctance.** The resistance of a magnetic path to the flow of magnetic lines of force through it.

**Eddy Currents.** Those currents induced in the body of a conducting mass by a variation in magnetic flux.

**Hysteresis.** The difference between the response of a unit or system to an increasing and a decreasing signal.

**$I^2R$ Losses.** The power loss in transformers, generators, connecting wires, and other parts of a circuit because of the current flow, I, through the resistance, R, of the conductors.

**Powdered Iron Core.** A core consisting of fine particles of magnetic material mixed with a suitable bonding material and pressed into shape.

**Domain.** A sphere of influence or activity.

**Autotransformer.** A single-coil transformer in which the primary and secondary are connected to the same coil.

**Tap.** A connection brought out from a winding at some point between its extremities, usually to permit changing the voltage ratio.

**Saturation.** When the domains of a magnetic material are completely aligned and no further increase in input voltage will produce an increase in magnetic flux.

## MATHEMATICAL EXPRESSIONS

$$E_s = 4.44\ fN_s\phi_m$$

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} = a$$

$$E_pI_p = E_sI_s$$

$$\frac{E_p}{E_s} = \frac{I_s}{I_p}$$

$$\frac{I_s}{I_p} = \sqrt{\frac{R_p}{R_s}}$$

$$\frac{I_s}{I_p} = \sqrt{\frac{Z_p}{Z_s}}$$

$$Z_p \simeq \left(\frac{N_p}{N_s}\right)^2 Z_L$$

$$a = \frac{E_p}{E_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}$$

$$P = I^2R = \frac{V^2}{R}$$

$$P_{losses} = P_{in} - P_{out}$$

## MATERIALS

1 Transformer, 240/480 to 120/240
1 Wattmeter
2 VOM meters
1 1000 Ω resistor, 25 watt
2 500 Ω resistors, 25 watt
1 Audio generator
1 Variable transformer

## DATA

| Frequency (in Hertz) | 0 | 10 | 35 | 60 | 600 | 6000 |
|---|---|---|---|---|---|---|
| $V_1$ | 0 | 5 | 5 | 5 | 5 | 5 |
| $V_2$ | 0 | 4.25 | 3.35 | 3.3 | 3.2 | 3.05 |
| Turns Ratio | | 1.175 | 1.495 | 1.515 | 1.56 | 1.64 |

| Frequency (in Hertz) | 0 | 10 | 35 | 60 | 600 | 6000 |
|---|---|---|---|---|---|---|
| $V_1$ | 0 | 5 | 5 | 5 | 5 | 5 |
| $V_2$ | 0 | 13 | 10 | 10 | 10.1 | 9.75 |
| Turns Ratio | | .385 | .5 | .5 | .495 | .513 |

*Fig. 6-15*

$R_L = 1000\ \Omega$

| $V_{in}$ | $P_{in}$ | $V_o$ | $P_{out}$ | $P_{loss}$ | Eff. | a |
|---|---|---|---|---|---|---|
| 25 | 1.1 W | 28.5 V | .812 W | .288 W | 73.8% | 1.14 |
| 50 | 4.74 | 55.5 | 3.08 | 1.67 | 64.9% | 1.11 |
| 75 | 10.4 | 82 | 6.72 | 3.68 | 64.6% | 1.09 |
| 95 | 17 | 104 | 10.8 | 6.2 | 63.6% | 1.095 |

$R_L = 500\ \Omega$

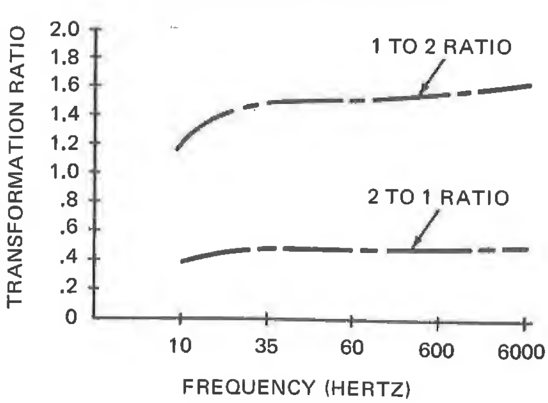
| $V_{in}$ | $P_{in}$ | $V_o$ | $P_{out}$ | $P_{loss}$ | Eff. | a |
|---|---|---|---|---|---|---|
| 25 | 1.8 W | 25 V | 1.25 W | .55 W | 69.5% | 1.0 |
| 50 | 7.7 | 47.6 | 4.53 | 3.17 | 58.9% | .953 |
| 75 | 17.3 | 70.5 | 9.94 | 7.36 | 57.5% | .94 |
| 95 | 26.5 | 90 | 16.2 | 10.3 | 63.6% | .947 |

$R_L = 250\ \Omega$

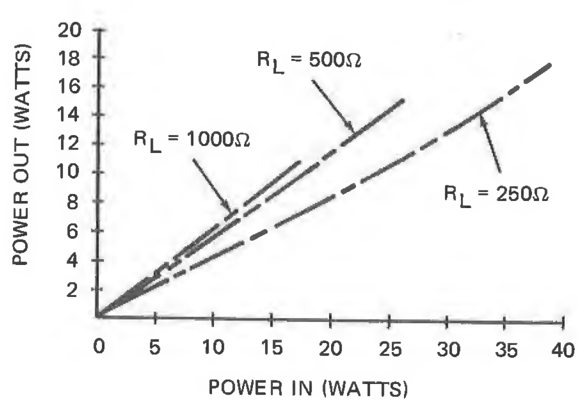
| $V_{in}$ | $P_{in}$ | $V_o$ | $P_{out}$ | $P_{loss}$ | Eff. | a |
|---|---|---|---|---|---|---|
| 25 | 2.8 W | 19 V | 1.445 W | 1.355 W | 51.6% | .76 |
| 50 | 12.2 | 36.5 | 5.32 | 6.98 | 43.6% | .731 |
| 75 | 26.25 | 53.5 | 11.2 | 15.05 | 42.6% | .707 |
| 95 | 39 | 67.2 | 18.05 | 20.95 | 46.3% | .715 |

*Fig. 6-17*

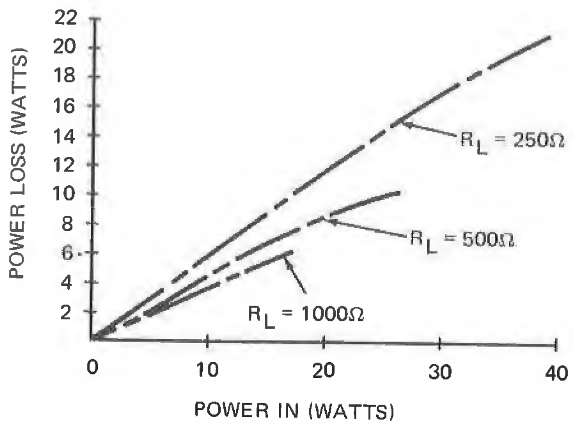
**GRAPH 1 FREQUENCY VS. TRANSFORMATION RATIO**



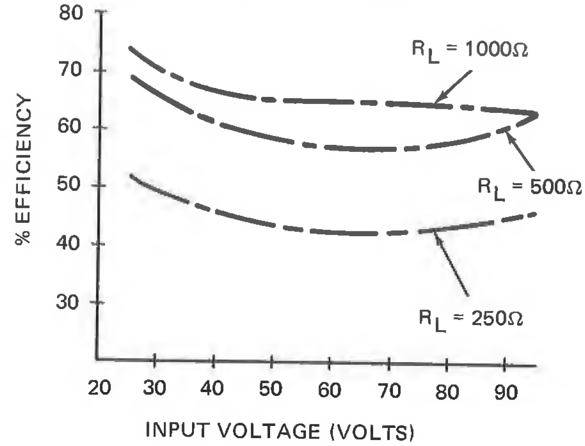

**GRAPH 2 POWER OUT VS. POWER IN**



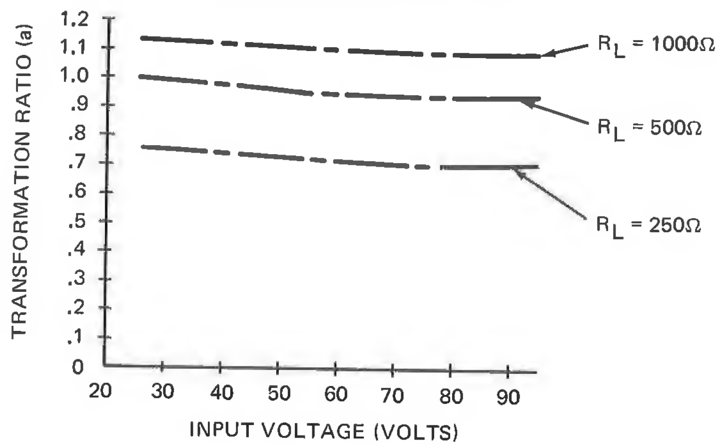
**GRAPH 3 POWER LOSS VS. POWER IN**




**GRAPH 4 % EFFICIENCY VS. INPUT VOLTAGE**




**GRAPH 5 INPUT VOLTAGE VS. TRANSFORMATION RATIO**




**ANALYSIS.** It should become apparent to the student that as the load resistance was decreased, the power out, efficiency, and the transformation ratio decreased also. This is due to the fact that, for a minimum amount of energy to be transferred from one circuit to another, the total impedance of both circuits must be equal. When $R_L$ was equal to 100 ohms, the greatest efficiency and power out was obtained.

**PROBLEMS**

1. A transformer substation is used to reduce the voltage from a 132,000-volt line to 3800 volts. The primary current is 38 amps. Determine the secondary current.

$$\frac{E_p}{E_s} = \frac{I_s}{I_p} \qquad \frac{132{,}000 \text{ volts}}{3{,}800 \text{ volts}} = \frac{I_s}{38 \text{ amps}}$$

$$I_s = \frac{(132{,}000 \text{ volts})\ (38 \text{ amps})}{3{,}800 \text{ volts}} = \mathbf{1{,}320 \text{ amps}}$$

2. If additional transformers were used to reduce the above voltage from 3800 volts to

115 volts, determine the secondary current.

$$\frac{3800 \text{ volts}}{115 \text{ volts}} = \frac{I_s}{38 \text{ amps}} \qquad I_s = \frac{(3800 \text{ volts})\ (38 \text{ amps})}{115 \text{ volts}} = \mathbf{1{,}255 \text{ amps}}$$

3. How does the voltage per turn on the primary compare with the voltage per turn on the secondary of a transformer?

From equation 6.8 $\dfrac{E_p}{E_s} = \dfrac{N_p}{N_s}$

For every volt per turn on the primary, the exact same ratio exists on the secondary windings. But for this to be true remember that equation 6.8 also states that

$$\frac{E_p}{E_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s}$$

The current ratio is inversely proportional to the voltage and turns ratio.

4. A transformer is required to step up a voltage from 120 to 540 volts. How many turns are required on the secondary winding if the primary has 180 turns?

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \qquad \frac{120 \text{ volts}}{540 \text{ volts}} = \frac{180 \text{ turns}}{N_s}$$

$$N_s = \frac{540 \text{ volts } (180 \text{ turns})}{120 \text{ volts}} = \mathbf{810 \text{ turns}}$$

**INTRODUCTION.** The student should learn how work is computed for mechanical and electrical systems. Static, dynamic, kinetic, and potential energies are examined for various systems.

## TECHNICAL TERMS

**Flywheel.** A heavy wheel for regulating the speed of the machine to which it is attached.

**Translational.** Uniform motion of a body in a straight line.

**Dynamic Energy.** Energy associated with motion. Synonymous with *kinetic energy* in a mechanical system.

**Static Energy.** The energy that a piece of matter has because of its position or because of its fixed arrangement. Synonymous with *potential energy* in a mechanical system.

## MATHEMATICAL EXPRESSIONS

$W = fD$

$W = (mg)h$

$s = \theta R$

$D = \ell_2 - \ell_1$

$f = QE$

$W = IVt$

$DE = \frac{1}{2}mV^2$

$DE = \frac{1}{2}I\omega^2$

$SE = \frac{1}{2}CV_2{}^2$

$f = mg$

$W = fs$

$W = T\theta$

$W = f(\ell_2 - \ell_1)$

$W = QV$

$P = \frac{W}{t}$

$SE = mgh$

$SE = \frac{1}{2}f_2x$

$DE = \frac{1}{2}LI_2{}^2$

$$\%\ \text{eff.} = \frac{W_o}{W_{in}} \times 100 \times \frac{P_o}{P_{in}} \times 100$$

## MATERIALS

1 Capacitor, 1 $\mu$F, 400 working volts
1 Capacitor, 2 $\mu$F, 400 working volts
1 Resistor, 10 kilohm, 2 watts
1 Resistor, 100 kilohms, 2 watts
1 Strip chart recorder, dual channel
1 Switch, SPDT

## DATA

C = 1 $\mu$F E = 50 volts

| | t | $V_c$ | $P_c$ |
|---|---|---|---|
| 0 RC | 0 sec | 50 V | 25 mW |
| 1 RC | .1 | 20 | 4 |
| 2 RC | .2 | 8 | .64 |
| 3 RC | .3 | 3 | .09 |
| 4 RC | .4 | 1 | .01 |
| 5 RC | .5 | 0 | 0 |

C = 1 $\mu$F E = 100 volts

| | t | $V_c$ | $P_c$ |
|---|---|---|---|
| 0 RC | 0 sec | 100 V | 100 mW |
| 1 RC | .1 | 40 | 16 |
| 2 RC | .2 | 16 | 2.56 |
| 3 RC | .3 | 6 | .36 |
| 4 RC | .4 | 2 | .04 |
| 5 RC | .5 | 0 | 0 |

*Fig. 7-7 Data Tables*

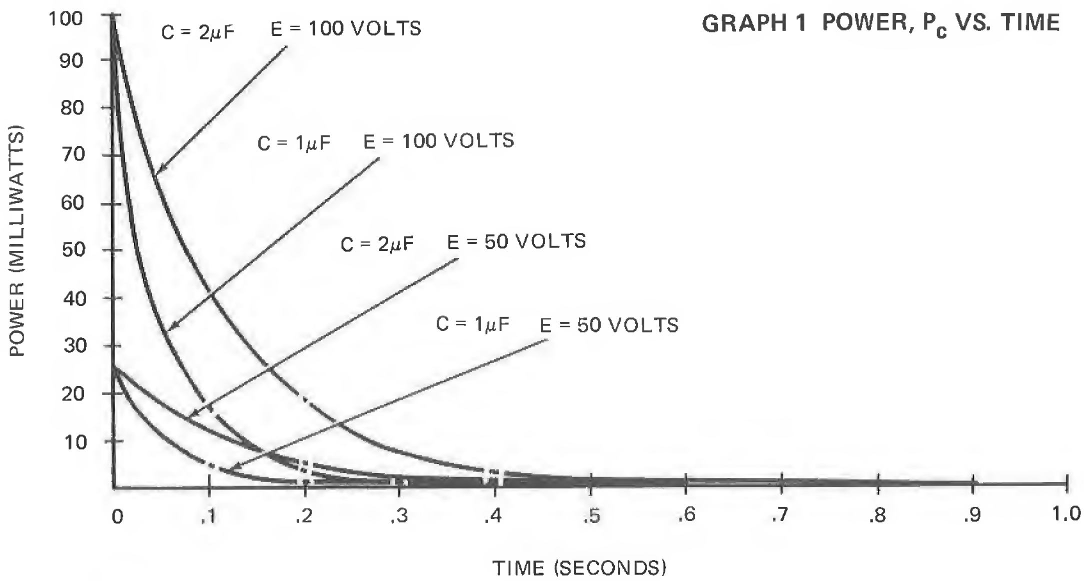
$C = 2\ \mu F$ $E = 50$ volts

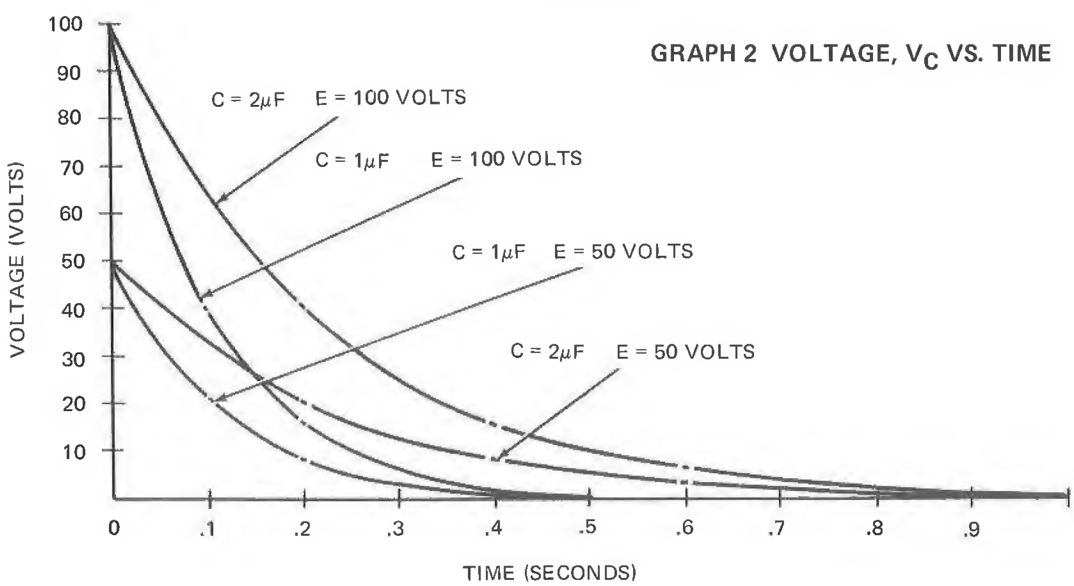
| | t | $V_C$ | $P_C$ |
|---|---|---|---|
| 0 RC | 0 sec | 50 V | 25 mW |
| 1 RC | .2 | 20 | 4 |
| 2 RC | .4 | 8 | .64 |
| 3 RC | .6 | 3 | .09 |
| 4 RC | .8 | 1 | .01 |
| 5 RC | 1.0 | 0 | 0 |

$C = 2\ \mu F$ $E = 100$ volts

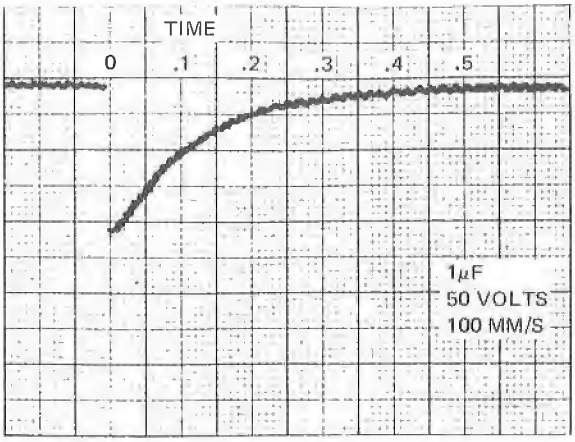
| | t | $V_C$ | $P_C$ |
|---|---|---|---|
| 0 RC | 0 sec | 100 V | 100 mW |
| 1 RC | .2 | 40 | 16 |
| 2 RC | .4 | 16 | 2.56 |
| 3 RC | .6 | 6 | .36 |
| 4 RC | .8 | 2 | .04 |
| 5 RC | 1.0 | 0 | 0 |

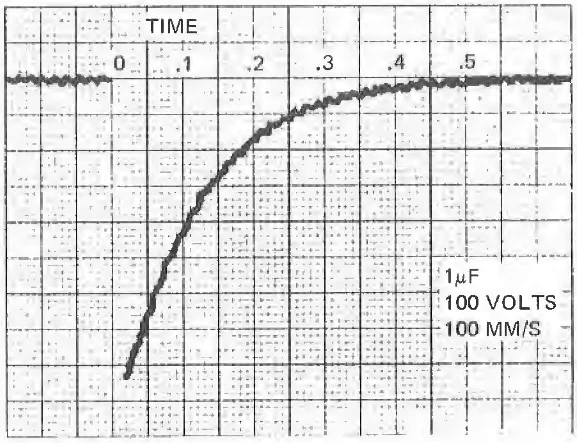
*Fig. 7-7 Data Tables (continued)*

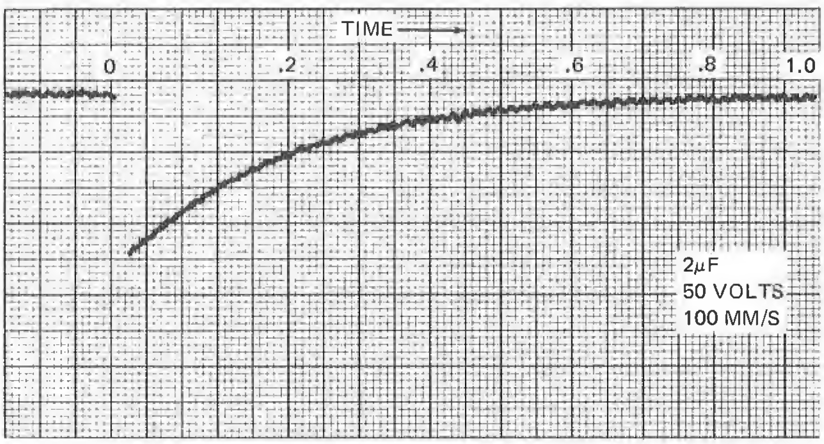


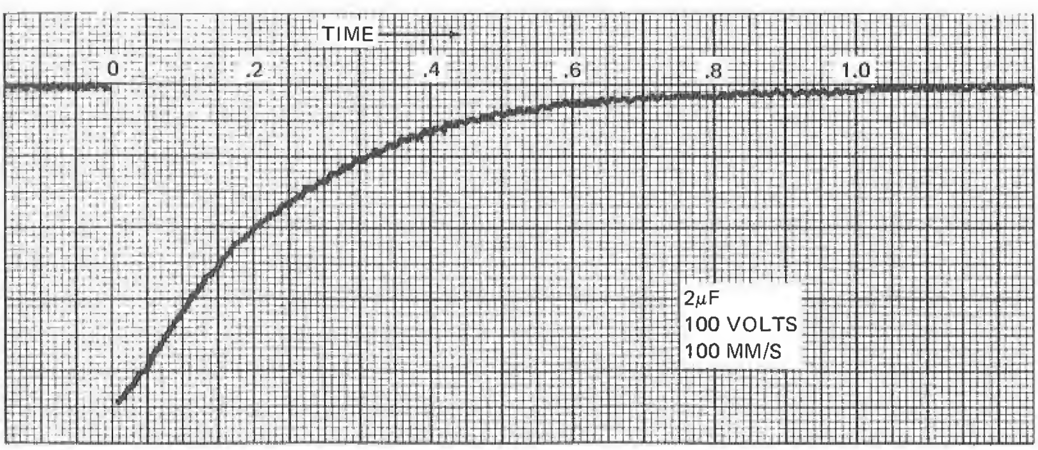



## DATA


TIME
0
.1
.2
.3
.4
.5
1μF
50 VOLTS
100 MM/S


TIME
0
.1
.2
.3
.4
.5
1μF
100 VOLTS
100 MM/S


TIME
0
.2
.4
.6
.8
1.0
2μF
50 VOLTS
100 MM/S


TIME
0
.2
.4
.6
.8
1.0
2μF
100 VOLTS
100 MM/S

**ANALYSIS.** The work done on the capacitor at each capacitance and voltage setting is:

$$\frac{1}{2}\,CE^2 = \frac{1}{2}\,(1\mu F)\,(50 \text{ volts})^2 = .00125 \text{ joules}$$

$$\frac{1}{2}\,CE^2 = \frac{1}{2}\,(2\mu F)\,(50 \text{ volts})^2 = .0025 \text{ joules}$$

$$\frac{1}{2}\,CE^2 = \frac{1}{2}\,(1\mu F)\,(100 \text{ volts})^2 = .005 \text{ joules}$$

$$\frac{1}{2}\,CE^2 = \frac{1}{2}\,(2\mu F)\,(100 \text{ volts})^2 = .010 \text{ joules}$$

From the power curves, the measured energy delivered by the capacitor is computed by the formula: area under the power curve in $cm^2$ X watt-sec/$cm^2$ = watt-seconds.

Remember that one watt-sec is equal to one joule.

When $C = 1\ \mu F$, $E = 50$ volts, Area = 2.60 $cm^2$

$$2.60 \text{ cm}^2 \times .5 \text{ mW-sec/cm}^2 = 1.30 \text{ mW-sec} = .0013 \text{ joules}$$

When $C = 2\ \mu F$, $E = 100$ volts, Area = 5.25 $cm^2$

$$5.25 \text{ cm}^2 \times .5 \text{ mW-sec/cm}^2 = 2.625 \text{ mW-sec} = .0026 \text{ joules}$$

When $C = 1\ \mu F$, $E = 100$ volts, Area = 10.30 $cm^2$

$$10.30 \text{ cm}^2 \times .5 \text{ mW-sec/cm}^2 = 5.150 \text{ mW-sec} = .0051 \text{ joules}$$

When $C = 2\ \mu F$, $E = 100$ volts, Area = 20.40 $cm^2$

$$20.40 \text{ cm}^2 \times .5 \text{ mW-sec/cm}^2 = 10.20 \text{ mW-sec} = .0102 \text{ joules}$$

From the above calculations, the work done charging the capacitor is approximately equal to the energy delivered by the capacitor. In an ideal situation, the computed value and the measured value would have been exactly equal. The difference is identified as the loss in the circuit.

From the response curves of the RC circuit, it should be noted that the voltage, $V_C$, never did indicate the maximum applied value because the strip-chart recorder arms had sufficient weight to prevent the instantaneous movement to the maximum voltage.

It is important that the student realize that the area under the power curve is the energy being delivered by the capacitor. The work done on the capacitor is the charge (energy stored in capacitor) caused by the applied voltage.

## PROBLEMS

1. Calculate the work involved in lifting a 2000-lb. weight up a 100-ft. oil derrick.

   Work = weight X height = 2000 lb X 100 ft = **200,000 ft-lbs**

2. Calculate the work involved in charging a 1-Henry inductor with 10 amps for 1 hour.

   $$W = \frac{1}{2}\text{ inductance} \times \text{current}^2 = \frac{1}{2}\,(1 \text{ Henry})\,(10 \text{ amperes})^2 = \mathbf{50\ joules}$$

3. Calculate the power required to lift the weight in problem 1, 50 feet in two seconds.

   Work = weight $\times$ height = 2000 lb $\times$ 50 ft = 100,000 ft-lbs

   $$\text{Power} = \frac{\text{Work}}{\text{Time}} = \frac{100{,}000 \text{ ft-lbs}}{2 \text{ seconds}} = \mathbf{50{,}000\ ft\text{-}lbs/sec}$$

4. Calculate the dynamic energy stored in a flywheel that has a moment-of-inertia of 1000 slugs-ft$^2$ and an angular velocity of 100 rad/second.

   $$\text{Dynamic energy} = \frac{1}{2}\ \text{inertia} \times \text{angular velocity}^2$$

   $$\text{DE} = \frac{1}{2}\ 1000 \text{ slugs-ft}^2 \times (100 \text{ rad/sec})^2 = \mathbf{5 \times 10^6\ joules}$$

5. Calculate the static energy stored in a $\mu$F capacitor that is charged to 100 volts DC.

   $$\text{Static energy} = \frac{1}{2}\ \text{capacitance} \times \text{average voltage}^2$$

   $$\text{SE} = \frac{1}{2}\ (1\ \mu\text{Farad})\ (100 \text{ volts})^2 = \mathbf{5 \times 10^{-3}\ joules}$$

**INTRODUCTION.** The student should learn relay action and ratings, relay contact arrangements, operating time, contact materials, and relay classifications so he can understand this electromechanical device.

## TECHNICAL TERMS

**Relay.** An electromechanical device in which contacts are opened and/or closed by variations in the conditions of one electric circuit. This thereby affects the operations of other circuits.

**Relay Coil.** A number of turns of wire wound around an iron core which, when energized, attracts the armature, thus opening or closing the contacts.

**Relay Contacts.** Contacts that are closed or opened by the movement of a relay armature.

**Relay Spring.** By acting on the relay armature, the spring tends to hold it in a given position.

**Static Energy.** Energy at rest or in equilibrium.

**Magnetomotive force (mmf).** The force by which a magnetic field is produced, either by a current flowing through a coil of wire or by the proximity of a magnetized body.

**Pull-in Current.** The coil current value that will cause the contacts to close.

**Flux Density.** The number of magnetic lines of force passing through a unit area.

**Drop-out Current.** The current value that will allow the contacts to open.

**Differential Current.** The difference between the pull-in current and the drop-out current.

**Impedance.** The total opposition (resistance and reactance) of a circuit to the flow of alternating current, measured in ohms.

**Inductive Reactance ($X_L$).** The opposition to the flow of alternating or pulsating current by the inductance of a circuit.

**Bounce.** The real action of any switch, relay, or contact to actually open or close several times in a millisecond when operated.

**Arcing.** The luminous discharge of electricity between conductors.

**Welding.** The joining of two metals, usually due to the application of heat.

**Conductivity.** The ability of a material to transmit energy (heat, electricity, light).

**Vaporization.** The gaseous formation of any substance normally a liquid or a solid.

**Oxide.** The increase in oxygen on the surface of a ferrous material which produces a micro-layer of highly non-conductive material.

**Hermetically Sealed.** The evacuating and sealing of an enclosure to make it airtight.

## MATHEMATICAL EXPRESSIONS

$f = 1.4 \times 10^{-8} B^2A$ $\qquad P = I^2R$ $\qquad Z = \sqrt{R^2 + X_L{}^2}$

$SE = \frac{1}{2} Kd^2$ $\qquad I_D = I_o - I_r$ $\qquad I = \frac{E}{R}$

$I = \frac{E}{Z}$ $\qquad f = d$ $\qquad P = EI \cos \theta$

## MATERIALS

1 Relay, 115 volts, open enclosure, PR3AY or equivalent
1 Ring stand and clamp assembly
1 Scale, 0–10 oz.
1 Spring, steel 1/8″ X 3/4″
1 Spring, steel 1/8″ X 1-3/4″
1 Ammeter, 0–150 mA DC
1 Ohmmeter
1 DC supply
1 Scale, 0–1′

## DATA

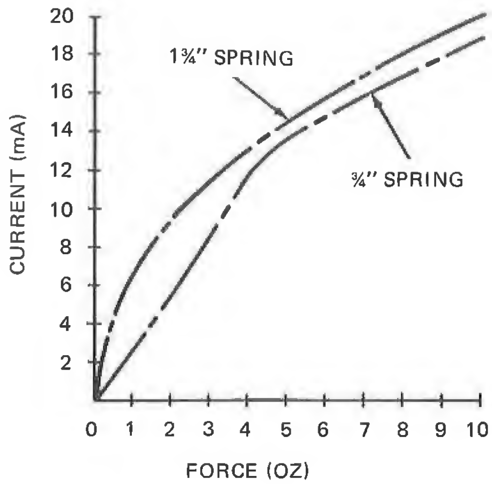
| Spring | Force, f | Current, I | Defl., d | Spring Constant k | Energy Storage SE |
|---|---|---|---|---|---|
| 3/4 in. | 1 oz. | 2.4 mA | .01 in. | 100 oz/in. | .005 in.-oz |
| | 2 oz. | 5.7 | .02 | 100 | .02 |
| | 4 oz. | 12 | .05 | 80 | .1 |
| | 6 oz. | 15 | .15 | 40 | .45 |
| | 8 oz. | 17 | .25 | 32 | 1 |
| | 10 oz. | 19 | .32 | 31.2 | 1.6 |
| 1-3/4 in. | 1 oz. | 7 mA | .005 in. | 200 oz/in. | .0025 in.-oz |
| | 2 oz. | 9.5 | .01 | 200 | .01 |
| | 4 oz. | 13 | .02 | 200 | .04 |
| | 6 oz. | 16 | .14 | 42.8 | .42 |
| | 8 oz. | 18 | .31 | 25.8 | 1.24 |
| | 10 oz. | 20 | .53 | 18.9 | 2.66 |

*Fig 8-5 Relay Opening*

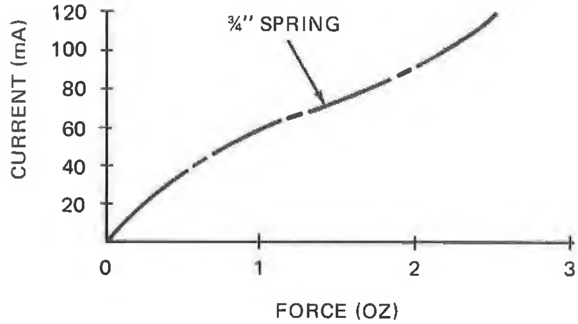
| Spring | Force | Current |
|---|---|---|
| 3/4 in. | 1 oz. | 59 mA |
| | 1.5 oz. | 74 |
| | 2.0 oz. | 90 |
| | 2.5 | 118 |
| | 3.0 | not obtainable |

*Fig. 8-6 Relay Closure*

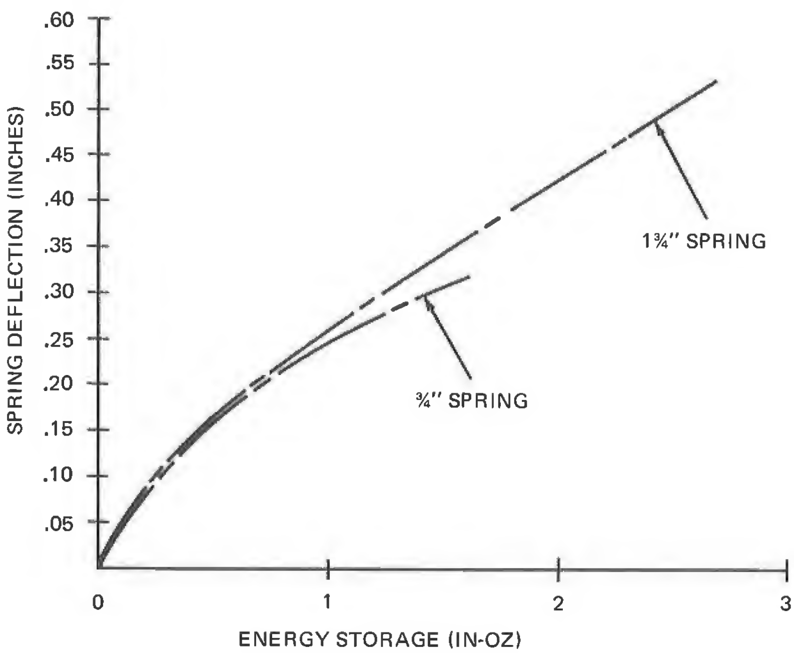
GRAPH 1 CURRENT VS. FORCE FOR RELAY OPENING




GRAPH 2 CURRENT VS. FORCE FOR RELAY CLOSING




GRAPH 3 SPRING DEFLECTION VS. ENERGY STORAGE




**ANALYSIS.** Graph 1 shows that the 1-3/4" spring required a small amount of current more than the 3/4" spring to open the relay. If both springs had the same spring constant, the lines would have been congruent.

Graph 2 shows that the current required to close the relay is nearly linear with the upward force against the armature.

The energy stored in the 3/4" spring in Graph 3 is nearly equal to the energy stored in the 1-3/4" spring.

## PROBLEMS

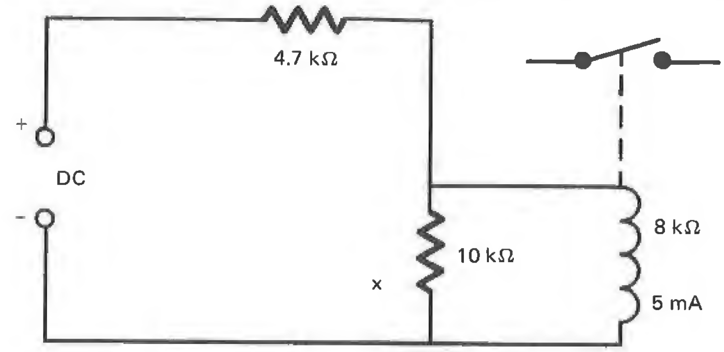
1. For the relay in figure 8-6, determine the source voltage required to cause the relay to pull in. The relay coil measures 8 k ohms and requires 5 mA for pull-in.

$$R_T = 4.7\text{ k}\Omega + \frac{(8\text{k}\Omega)\ (10\text{k}\Omega)}{(8\text{k}\Omega) + (10\text{k}\Omega)} = 4.7\text{ k}\Omega + 4.45\text{ k}\Omega = 9.15\text{ k}\Omega$$

$$\frac{5\text{ mA}}{x} = \frac{8\text{ k}\Omega}{10\text{ k}\Omega} = \frac{5\text{ mA }(10\text{ k}\Omega)}{8\text{ k}\Omega} = 6.25\text{ mA}$$

$$I_{total} = 5\text{ mA} + 6.25\text{ mA} = 11.25\text{ mA}$$

$$DC = I_{total} \times R_{total} = 11.25\text{ mA} \times 9.15\text{ k}\Omega = \mathbf{103\ volts\ DC}$$

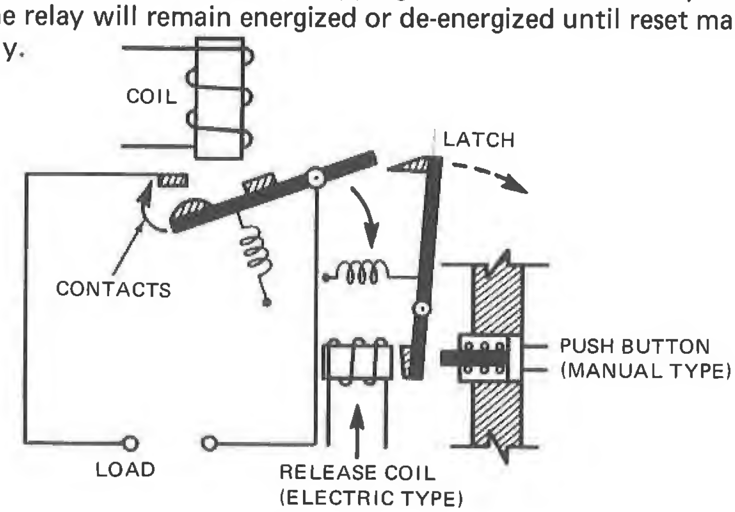



2. Using the library, find out how much the relays used in this experiment cost. If you cannot find the exact relay, determine the cost of a replacement as closely like the one used as possible. Include the detailed specifications found in the catalog.

| | |
|---|---|
| Potter and Brumfield | 25 amp Silver contacts, SPST |
| Franklin, Ky. | Coil resistance-290 ohms |
| Type PR3AY | Size-2-1/2" wide X 2-7/32" X 2-1/2" |
| 115 volt AC, 50/60 Hertz | Cost $4.55 |

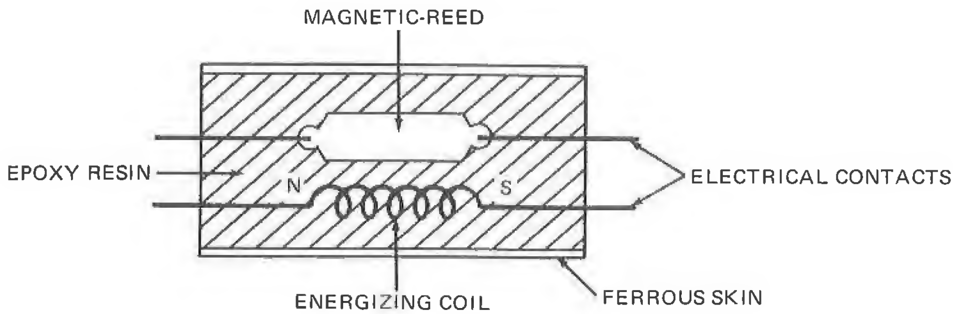
3. If there are severe fluctuations in the coil voltage of a relay, there would be the possibility of the relay dropping out. What type relay would you use to prevent this possibility? Discuss in detail how it works.

One type of relay that prevents "dropping out" is a catch-in relay or locking relay. The relay will remain energized or de-energized until reset manually or electrically.



4. One type of relay used when extremely rapid switching is required (speeds within several microseconds are possible) is the "magnetic-reed" relay. Explain how this type relay operates.

   A magnetic-reed relay is a magnetic-reed switch actuated by a DC magnetizing coil. The entire assembly is encapsulated in epoxy resin and it is often shielded against stray magnetic fields by a ferrous outer wrap.



**INTRODUCTION.** The student should learn the parts of a generator and how energy can be produced and stored.

## TECHNICAL TERMS

**Generator.** A device which converts mechanical energy into electrical energy.

**Prime Mover.** The self-moving device that is the source of motion for a system.

**Rotating Mass.** A body or material turning about an axis or center.

**Angular Velocity.** The rate at which an angle changes. Expressed in radians per second and designated by the Greek letter omega ($\omega$).

**Inertia.** A property of matter by which it remains at rest or in uniform motion in the same straight line unless acted upon by some external force.

**Power.** The rate at which work is being done, expressed in lb-ft/sec.

**Torque.** A turning or twisting force measured by the product of the force and the perpendicular distance from the line of action of the force to the axis of rotation, expressed in lb-ft.

**Magnetic Field.** An area where magnetic forces can be detected around a permanent, natural, or electromagnet.

**Armature.** The moving element in an electromechanical device such as the rotating part of a generator or motor.

**Slip Ring.** A device for making electrical connections between stationary and rotating contacts.

**Brush.** A piece of conductive material, usually carbon or graphite, which rides on the commutator of a motor and forms the electrical connection between it and the power source.

**Rectified.** The conversion of alternating current into unidirectional or direct current.

**Commutator.** The part of the armature to which the coils of a motor are connected. It consists of wedge-shaped copper segments arranged around a steel hub and insulated from it and one another. The brushes ride on the outer edges of the commutator bars and thereby connect the armature coils to the power source.

**Instantaneous Voltage.** The value of voltage at any particular instant.

**Lefthand Rule.** Also known as Fleming's Rule. If the thumb and the first and second fingers are extended at right angles to one another, with the thumb representing the direction of the wire motion, the first finger representing the direction of magnetic lines of force (from the north pole to the south pole), and the second finger representing the direction of the current, then the right hand will give the correct relationships for a conductor in the armature of a motor. This rule is applied to the so-called conventional current flow, which is the opposite of electron flow.

**Tension.** *Mechanical:* The condition of strain which tends to stretch. *Electrical:* The potential or electrostatic voltage.

**Self-Excited.** The supplying of field current to a generator from its own armature.

**Separately Excited.** Excitation in which the generator field current is provided by an independent source or motor field. Current is provided from a source other than the one connected across the armature.

**Residual Magnetism.** The magnetism which remains in the core of an electromagnet after the operating circuit has been opened.

**Alternators.** A generator designed to supply AC current.

**Exciter.** A small, auxiliary generator that provides field current for an AC generator.

**Single-Phase.** A generator which produces a single, alternating electromotive force at its terminals.

**Two-Phase.** A generator having a phase difference of 90 electrical degrees, or one quarter-cycle between the output terminals.

**Three-Phase System.** A combination of circuits energized by alternating electromotive forces which differ in phase by one-third of a cycle, or 120 electrical degrees.

**Delta.** A three-phase system whose main advantage is that increased power can be obtained without a corresponding increase in individual voltages and currents. The system resembles the Greek letter delta (Δ).

**Wye.** A three-phase system whose construction is in the form of a Y (wye). The wye system has the same advantage as a delta system.

## MATHEMATICAL EXPRESSIONS

$$KE = \frac{1}{2} I\omega^2$$

$$I = \frac{1}{2} mr^2$$

$$\omega = \frac{P}{T}$$

$$\omega' = \frac{60\,\omega}{2\,\pi} \text{ RPM}$$

$$I = \frac{1}{2}\left(\frac{w}{g}\right) r^2$$

$$e = N\frac{\Delta\theta}{\Delta t}$$

$$e = \frac{\phi \overline{P}(RPS)Z}{P\,10^8}$$

$$f = \frac{\overline{P}(RPS)}{7200}$$

$$\%\ \text{eff.} = \frac{P_o}{P_{in}} \times 100$$

## MATERIALS

1 Motor, DC, 28 volts, 1/100 HP, 7000 RPM
1 Generator, 3.8 volts/100 RPM, 6000 RPM
1 Supply, 0-28 volts, DC
1 Recorder, strip chart
1 Resistor, 5 kilohm, 2 watts
1 VOM
1 Switch, SPST
1 Coupling, generator shaft to motor shaft

## DATA

s = 1500 RPM

| E | e | V/mm | mm/s | t | I | P |
|---|---|---|---|---|---|---|
| 16.1 V | 3.5 V | .30 | 100 | .002 s | .7 amp | 2.45 W |
| | 52.8 | 4.4 | 100 | .001 | 10.5 mA | .555 |
| | 35.2 | 4.4 | 100 | .006 | 7.04 | .248 |
| | 22.0 | 4.4 | 100 | .011 | 4.4 | .097 |
| | 4.4 | 4.4 | 100 | .017 | .88 | .0038 |

*Fig. 9-10 Data Table*

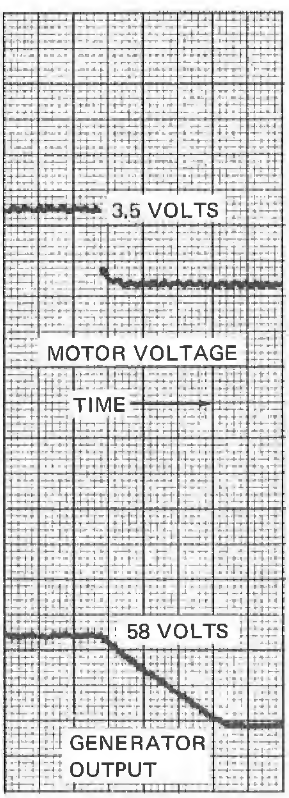
s = 2500 RPM

| E | e | V/mm | mm/s | t | I | P |
|---|---|---|---|---|---|---|
| 20.5 V | 3.75 V | .30 | 100 | .002 s | .75 amp | 2.81 W |
| | 88 | 4.4 | 100 | .002 | 17.6 mA | 1.55 |
| | 66 | 4.4 | 100 | .007 | 13.2 | .87 |
| | 48.4 | 4.4 | 100 | .012 | 9.7 | .465 |
| | 13.2 | 4.4 | 100 | .022 | 2.64 | .034 |

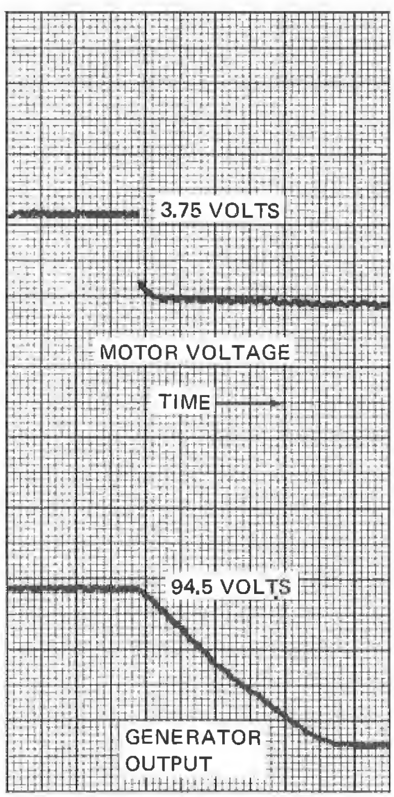
s = 3500 RPM

| E | e | V/mm | mm/s | t | I | P |
|---|---|---|---|---|---|---|
| 26 V | 4.05 V | .30 | 100 | .002 s | .81 amp | 3.28 W |
| | 123 | 4.4 | 100 | .002 | 24.6 mA | 3.03 |
| | 74.8 | 4.4 | 100 | .012 | 15 | 1.12 |
| | 35.2 | 4.4 | 100 | .022 | 7.04 | .248 |
| | 4.5 | 4.4 | 100 | .032 | .88 | .038 |

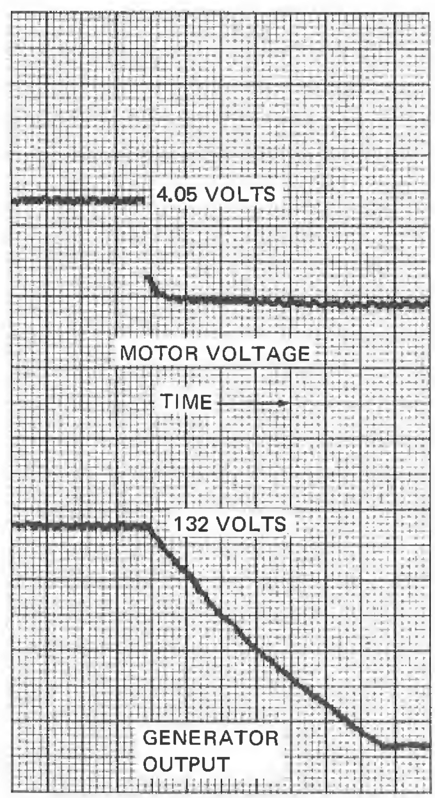
*Fig. 9-10 Data Tables (continued)*



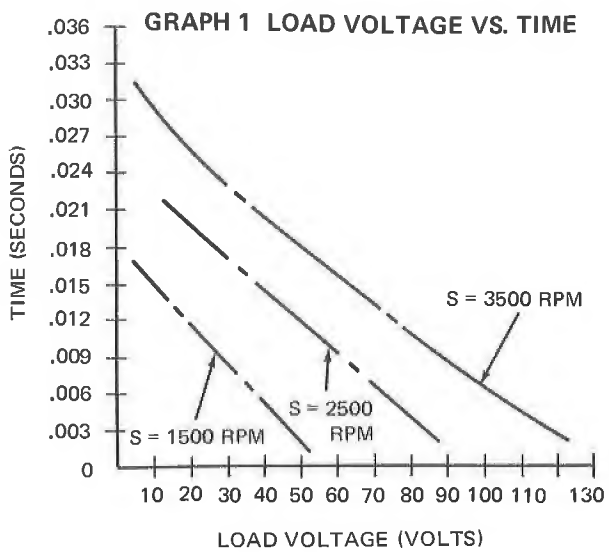

100 mm/sec
1500 RPM

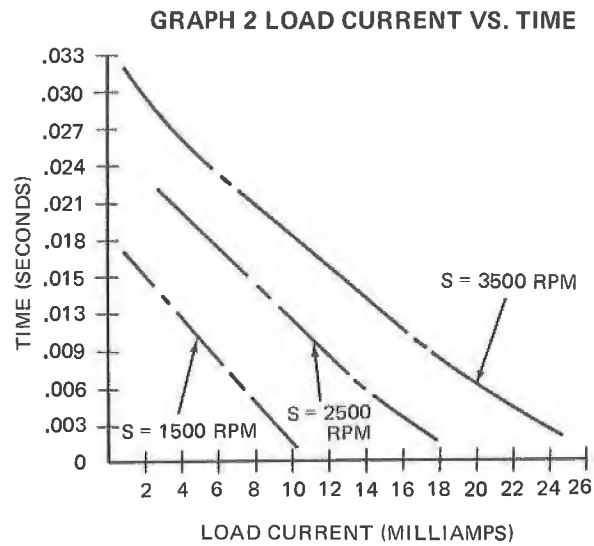


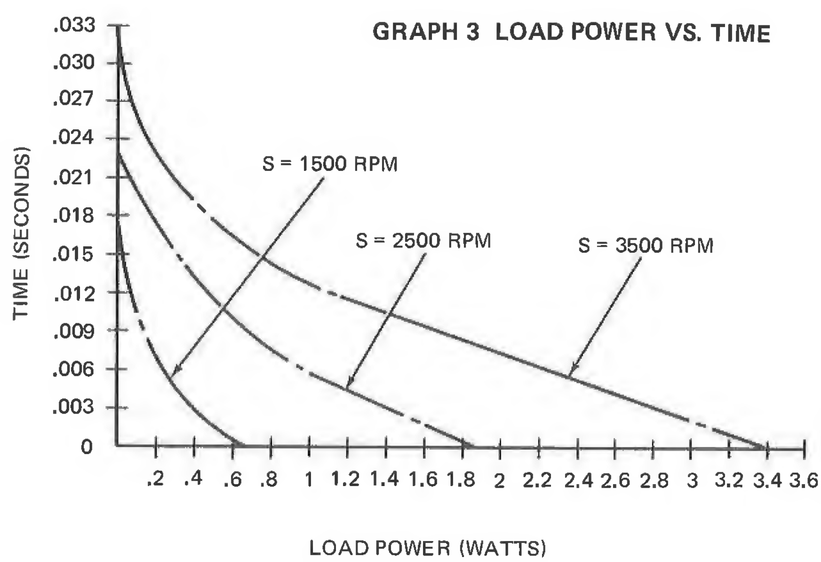

100 mm/sec
2500 RPM




100 mm/sec
3500 RPM




**ANALYSIS.** To accurately calculate the stored energy under each power curve, calculus should be used. But an easier way to measure the stored energy is to count the total area in centimeters under each curve and multiply by the watt-sec/cm constant. The watt-sec/cm constant is equal to the time per cm times the load per cm.

The stored energy of the system when the speed was 1500 RPM is

$5.88\ cm^2 \times .0006\ watts\text{-}sec/cm^2 = .00353\ watt\text{-}sec.$

When the speed was increased to 2500 RPM, the stored energy is

$23.71\ cm^2 \times .0006\ watt\text{-}sec/cm^2 = .0138\ watt\text{-}sec.$

For a speed of 3500 RPM, the stored energy is

$56.65\ cm^2 \times 0.0006\ watt\text{-}sec/cm^2 = 0.0336\ watt\text{-}sec.$

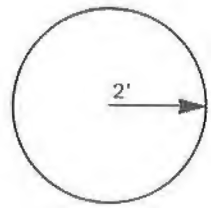
**PROBLEMS**

1. A plastic hoop has a radius of 2 ft and weighs 8 ounces. Calculate its moment of inertia.

$$I = \frac{1}{2}\left(\frac{w}{g}\right) r^2 = \frac{1}{2}\left(\frac{.5 \text{ lb}}{32 \text{ ft/sec}^2}\right) 4 \text{ ft}^2$$

$$= \frac{1}{2}(.0156 \text{ slug})\ 4 \text{ ft}^2 = (.0078 \text{ slugs})\ 4 \text{ ft}^2$$

$$= \mathbf{.0312\ slug\text{-}ft^2}$$



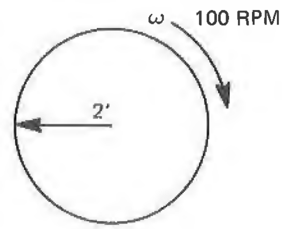

WEIGHT = 8 OZ.

2. Calculate the dynamic energy stored in the hoop of problem 1, if its angular velocity is 100 RPM.

$$DE = \frac{1}{2} I \omega^2 = \frac{1}{2}(.0312 \text{ slug-ft}^2)\ \omega^2$$

$$= \frac{1}{2}(.0312 \text{ slug-ft}^2)\ 10.46 \text{ radians/sec}$$

$$= \mathbf{.1631\ joules}$$




3. An automobile engine exerts a torque of 250 lb-ft at 400 RPM on its crankshaft. Calculate the horsepower developed by the engine.

$$\omega = \frac{2\pi\omega'}{60} = \frac{6.28\ (4000 \text{ RPM})}{60} = 418.6 \text{ radians/sec}$$

$$\text{Power} = \text{torque}\ (\omega) = 250 \text{ lb-ft}\ (418.6 \text{ radians/sec}) = 104{,}500 \text{ lb-ft/sec}$$

$$1 \text{ horsepower} = 550 \text{ lb-ft/sec}$$

$$HP = \frac{104{,}500 \text{ lb-ft/sec}}{550 \text{ lb-ft/sec}} = \mathbf{190}$$

4. The tire of a boat trailer is 18 inches in diameter. If the tire is rotating at 1500 RPM, what is its angular velocity and the linear speed of a point on the tread?

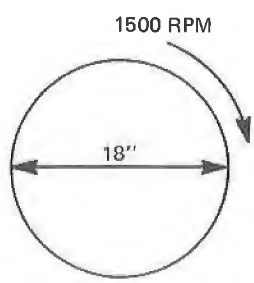
$$\omega = \frac{2\pi\omega'}{60} = \frac{6.28\ (1500 \text{ RPM})}{60}$$

$$= \mathbf{157\ radians/sec}$$

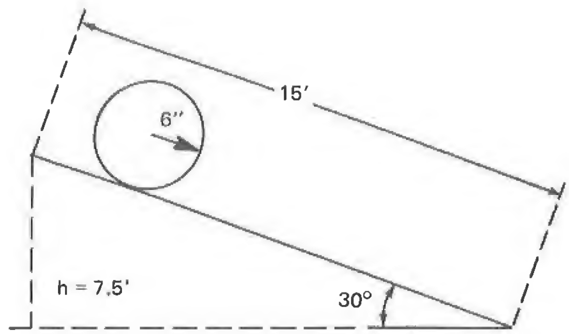
$$\text{Linear speed } (v) = \omega r$$

$$v = 150 \text{ radians/sec (9 inches)} = 1350 \text{ inches/sec}$$

$$= \mathbf{112.5\ ft/sec}$$




5. A 10-pound cylinder with a radius of six inches rolls down a loading ramp 15-feet long that is at an angle of 30° to the horizontal. Determine its angular velocity and linear velocity at the bottom of the ramp. What is the static energy stored in the cylinder before it moves down the plane? What is the rotational energy and the translational energy of the cylinder at the bottom of the ramp?




Static Energy = Dynamic Energy

Static Energy = translational energy + rotational energy

$$mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$

$$(.313 \text{ slugs})(32.2 \text{ ft/sec}^2)\,7.5 \text{ ft} = \frac{1}{2}(.313 \text{ slugs})\,v^2 + \frac{1}{2}(.0391 \text{ slug-ft}^2)\left(\frac{v}{.5 \text{ ft}}\right)^2$$

$$(10 \text{ slug-ft/sec}^2)\,7.5 \text{ ft} = .1565 \text{ slugs } v^2 + .0195 \text{ slug-ft}^2 \left(\frac{v^2}{.25 \text{ ft}^2}\right)$$

$$75 \text{ slug-ft}^2/\text{sec}^2 = .1565 \text{ slug } v^2 + .0049 \text{ slugs } v^2$$

$$75 \text{ slug-ft}^2/\text{sec}^2 = .1614 \text{ slugs } v^2$$

$$v^2 = \frac{75 \text{ slug-ft}^2/\text{sec}^2}{.1614 \text{ slug}} = \frac{75 \text{ ft}^2/\text{sec}^2}{.1614}$$

$$v = \sqrt{465 \text{ ft}^2/\text{sec}^2} = 21.6 \text{ ft/sec}$$ Linear velocity at bottom of plane

$$\omega = \frac{v}{r} = \frac{21.6 \text{ ft/sec}}{.5 \text{ ft}} = 43.3 \text{ radians/sec}$$ Angular velocity at bottom of plane

Static Energy = mgh

SE = (.313 slugs)(32.2 ft/sec$^2$)(7.5 feet) = **75 slug-ft$^2$/sec$^2$**

Dynamic rotational energy $= \frac{1}{2} I\omega^2$

DE $= \frac{1}{2}$ (.0391 slug-ft$^2$) 43.3 radians/sec = **.845 radian-slug-ft$^2$/sec**

Translational energy $= \frac{1}{2}mv^2$

TE $= \frac{1}{2}$ (.313 slugs)(21.6 ft/sec$^2$) = (.1565 slugs) 465 ft$^2$/sec$^2$

= **72.8 slugs-ft$^2$/sec$^2$**

## instructor's guide 10 RELAY TIME CONSTANTS

**INTRODUCTION.** The student should learn: how relays work, contact arrangements, relay time constants and exponential curves.

### TECHNICAL TERMS

**Magnetic Loops (magnetic lines of force).** In a magnetic field, the imaginary lines which have the direction of the magnetic flux at every point.

**Permeable.** The measure of how much better a given material is than air as a path for magnetic lines of force.

**Poles.** The output terminals of an electric cell, relay, switch or dynamo.

**Throws.** To make or break a connection.

**Normal Position.** A contact which in its normal position closes a circuit and permits current to flow.

**Normally Open (NO).** Designation applied to the contacts of a switch or relay when they are connected so that the circuit will be broken when the switch is not activated or the relay coil is not energized.

**Normally Closed (NC).** Designation applied to the contacts of a switch or relay when they are connected so that the circuit will be completed when the switch is not activated or the relay coil is not energized.

**Oxides.** Commonly known as rust when ferrous material is involved. Results from the increase in oxygen on the surface of a metal. It provides a very good insulating layer.

**Time Constant.** The time required for an exponential quantity to change by an amount equal to 0.632 times the total change that will occur.

**Kirchhoff's Voltage Law.** The algebraic sum of the voltage drops in any closed path in a circuit is equal to the algebraic sum of the electromotive forces in that path.

**Initial Rate-of-Change.** The beginning or first change in a quantity per unit of time.

### MATHEMATICAL EXPRESSIONS

$$\tau_{elec} = \frac{L}{R}$$

$$V_c = V_o(\epsilon^{-t/RC})$$

$$i_L = i_o(\epsilon^{-tR/L})$$

$$V_c = V_o(1 - \epsilon^{-t/RC})$$

$$i_L = i_o(1 - \epsilon^{-tR/L})$$

$$Y = Y_m - (Y_m - Y_o)\epsilon^{-x}$$

### MATERIALS

1 DC power supply
1 Single pole-double throw relay
1 Oscilloscope
1 15 Ω resistor, 1/2 watt
1 VOM

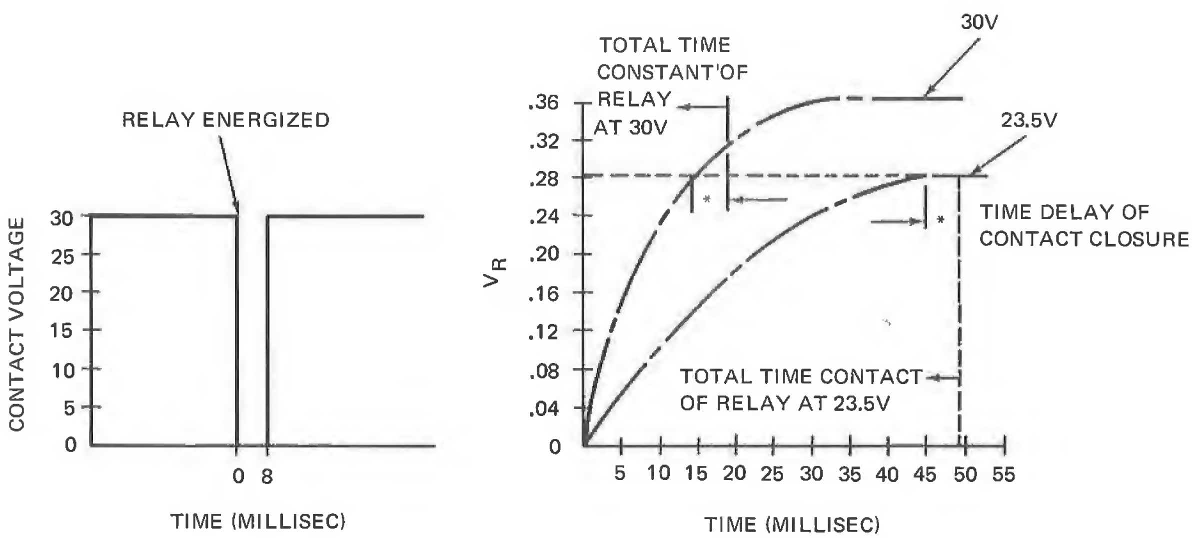
## DATA

| Relay Data |
|---|
| Energized at 23.5 V |
| $V_R$ = .28 volts |

| Voltage | 23.5 V | 30 V |
|---|---|---|
| Relay Time Constant | 15 ms | 45 ms |
| Time Delay of Constant Closure | 8 ms | |

*Fig. 10-18*

**GRAPH RELAY TIME CONTACTS AND TIME DELAY OF CONTACT CLOSURE**



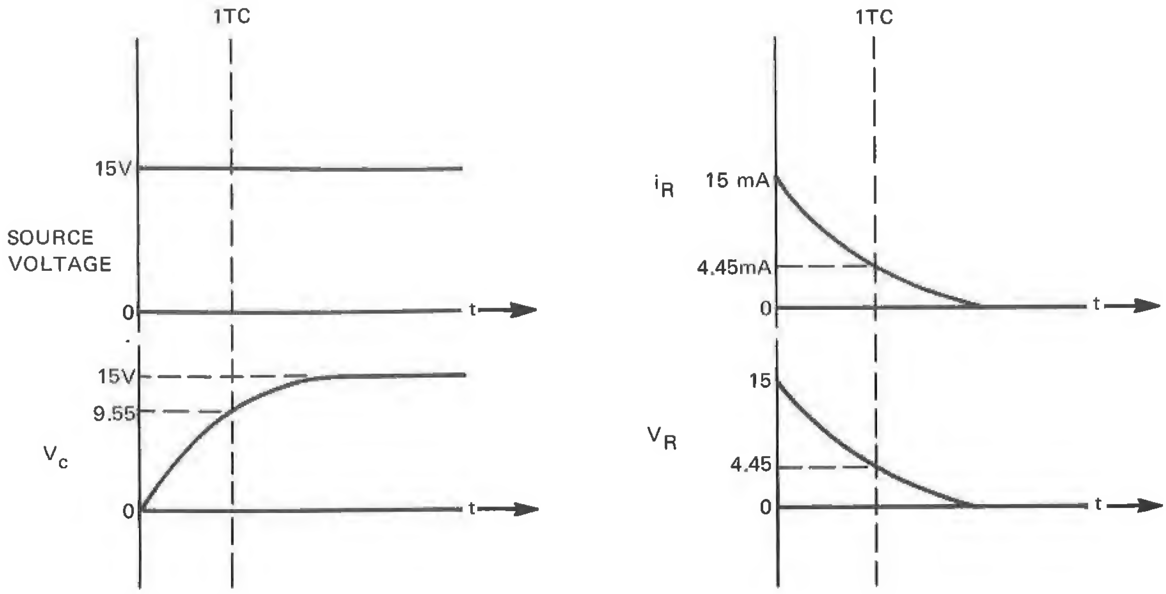

**ANALYSIS.** A relay uses a coil of wire with a soft iron core as an electromagnet to attract another ferrous material (the armature) when supplied with a sufficient amount of current. The armature is connected to a contact arrangement which energizes or de-energizes another circuit or circuits.

Whenever the relay is actuated, the time delay of the relay will slow down the signal being controlled, measured, or transmitted. This delay is the relay time constant.

For example, an automatic control system that is being used aboard a test rocket requires the use of relays to cause the first stage to be jettisoned. Because of the acceleration needed to escape the earth's gravity, the time interval between the shut-down of the first stage and the starting of the second stage engines is very critical. Therefore, the speed at which the relay can operate affects the entire rocket trajectory.

**PROBLEMS**

1. Plot the waveforms for the RC circuit shown in figure 10-19 in time sequence.




2. Determine the time constant of the circuit in problem one.

   Time Constant = Resistance X Capacitor

   TC = RC = (1 kilohm)(2 $\mu$Farads) = **2 milliseconds**

3. Write the equations describing the rise or delay of $V_c$, $V_R$ and $i_R$ for the waveforms in problem one.

   $$V_c = 15 \text{ volts } (1 - \epsilon^{-t/2ms})$$

   $$V_R = 15 \text{ volts } (\epsilon^{-t/2ms})$$

   $$i_R = 15 \text{ mA } (\epsilon^{-t/2ms})$$

**INTRODUCTION.** The student should review basic motor action and learn what motor time constants are and their electrical counterpart.

## TECHNICAL TERMS

**Normal.** Perpendicular at a point.

**Axial.** Situated around, in the direction of, on, or along an axis.

**Tangential Force.** A force acting at right angles to a radius.

**Stator.** The non-rotating part of the magnetic structure in an induction motor. It usually contains the primary winding.

**Rotor.** The rotating member of an electrical machine. In a motor, it is connected to and turns the drive shaft.

**Time Lag.** The interval between application of any force and full attainment of the resultant effect.

**Time Constant.** The time required for an exponential quantity to change by an amount equal to 0.632 times the total change that will occur.

**Mechanical Time Constant.** The exponential change in a quantity due to the mass of the armature and conductors and the resistance due to friction in the rotor's bearings.

**Electrical Time Constant.** The exponential change in voltage or current due to the result of the resistance and the inductance of the armature windings.

**Torque.** In a force, the product of the force and its perpendicular distance from the axis of its rotation to its line of action.

**Kirchhoff's Voltage Law.** The algebraic sum of the voltage drops in any closed path in a circuit is equal to the algebraic sum of the emfs in that path.

**Inertia.** The tendency of an object at rest to remain at rest, or of a moving object to continue moving in the same direction and at the same speed, unless disturbed by an outside force.

**Moment of Inertia.** The resistance which a body offers to angular acceleration.

**Friction.** The resistance to motion between two bodies in contact.

**Kinetic Energy.** Energy associated with motion.

**Strip Chart Recorder.** An instrument which monitors the changes of a variable by means of a single continuous line on a long strip of paper.

## MATHEMATICAL EXPRESSIONS

$$T = K\phi_p I_a \qquad I_m = \frac{E_m}{R}$$

$$\tau = \frac{L}{R} \qquad i_a = i_L = i_R = i_o(1 - \epsilon^{-t/\tau})$$

$$T = K\phi_p i_o(1 - \epsilon^{-tR/L}) \qquad I = mr^2$$

$$T = I\alpha \qquad KE = \frac{1}{2} I\omega^2$$

$$\omega = \omega_o (1 - \epsilon^{-t/\tau})$$

$$\tau = \frac{I}{B}$$

$$\omega = \omega_o \, \epsilon^{-t/\tau}$$

$$KE = \frac{1}{2} I (\omega_o \epsilon^{-tB/I})^2$$

## MATERIALS

1 VOM
2 28-volt DC motors, 15,000 RPM, 0.6 amps
1 Motor shaft coupling
1 DC power supply
1 10 kilohm resistor
1 Stroboscope
1 Single pole, double throw switch
1 Sheet graph paper, 10 X 10 divisions in cm
1 Strip chart recorder
3 Flywheels, different sizes

## DATA

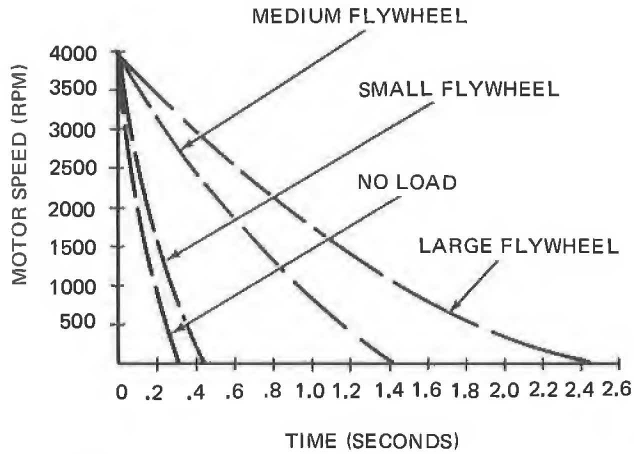
| Load | Time Constant |
|---|---|
| No load | .14 sec |
| Small flywheel | .20 sec |
| Medium flywheel | .72 sec |
| Large flywheel | 1.13 sec |

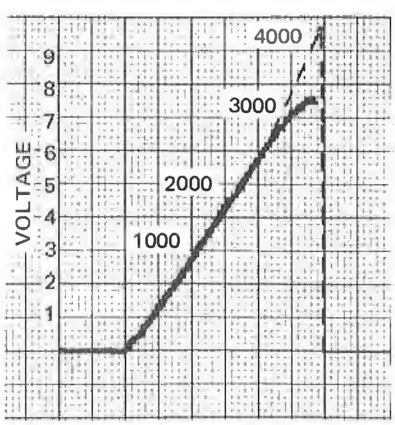
*Fig. 11-16 Data Table*

| RPM | Voltage |
|---|---|
| 5000 | 12.7 V |
| 4000 | 9.7 V |
| 3000 | 7.2 V |
| 2000 | 4.9 V |
| 1000 | 3.6 V |
| 0 | 0 |

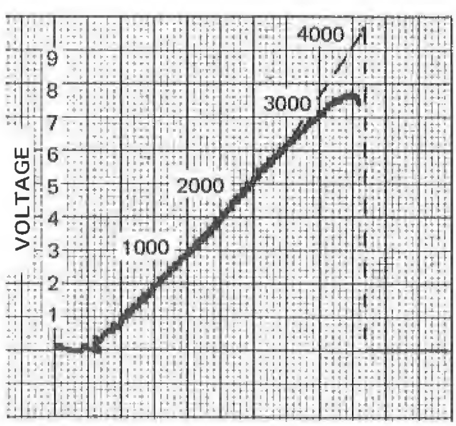
Data table of output voltage versus RPM

**GRAPH MOTOR SPEED VS. TIME**

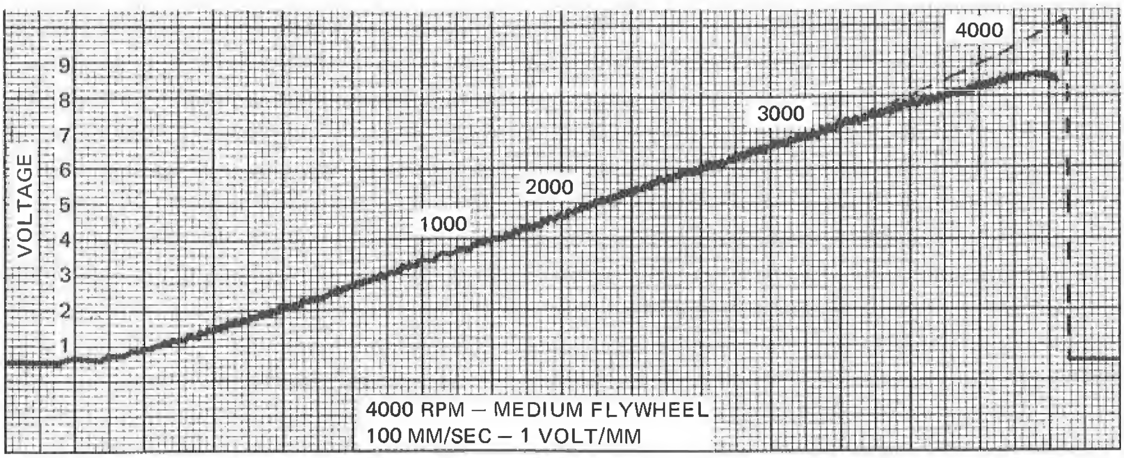


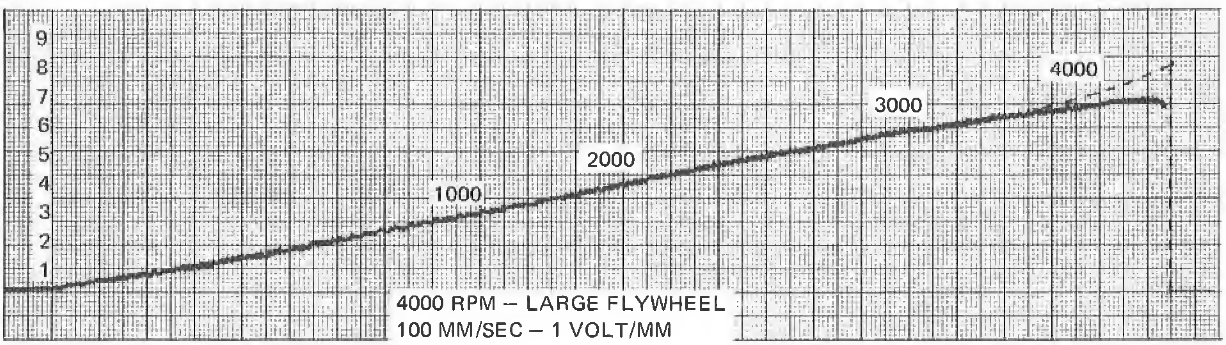




4000 RPM – NO LOAD
100 MM/SEC – 1 VOLT/MM




4000 RPM – SMALL FLYWHEEL
100 MM/SEC – 1 VOLT/MM




**ANALYSIS.** As a motor is supplied electrical energy, the speed increases in proportion to the input voltage. The increased speed results in increased torque.

$$T = I\alpha$$

Because mechanical torque is equivalent to current in an electrical system, an exponential curve will show the increase or decrease in torque with respect to time. These curves are a measure of the time lag of the motor.

From Graph, Motor Speed vs. Time, it is apparent that with the increase in mass of the rotor, a longer time lag results. Obviously, the curves do not resemble smooth exponential curves but the similar response does show the action of the motor.

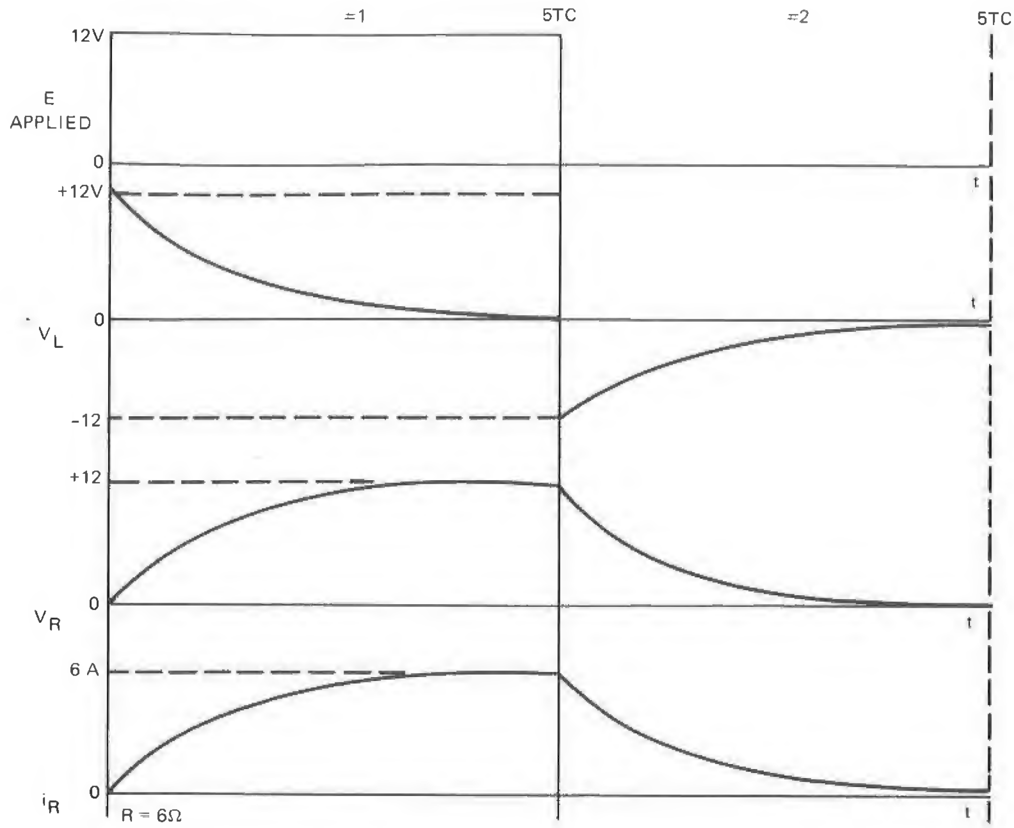
The effect of time lag in a system which requires near instantaneous changes from minimum to maximum speed are; delays in operations or functions, delays in process actions or positioning, failure of units to provide corrective or informative signals accurately.

**PROBLEMS**

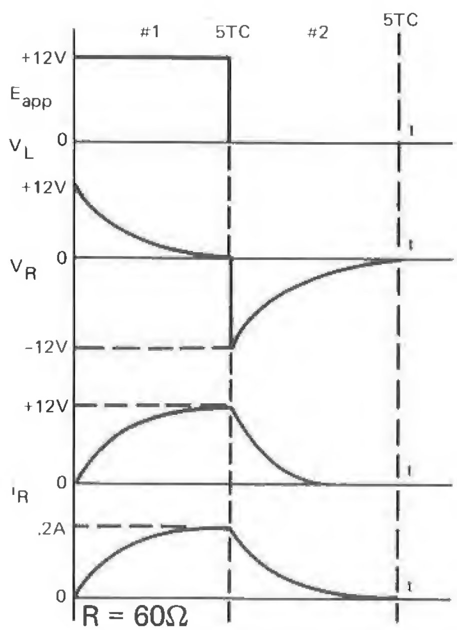
1. Determine the electrical time constant of a motor which has 100 Ω of resistance and 200 Henrys inductance in the armature windings.

$$\tau = \frac{L}{R} = \frac{200 \text{ Henrys}}{100 \text{ ohms}} = \textbf{2 seconds}$$

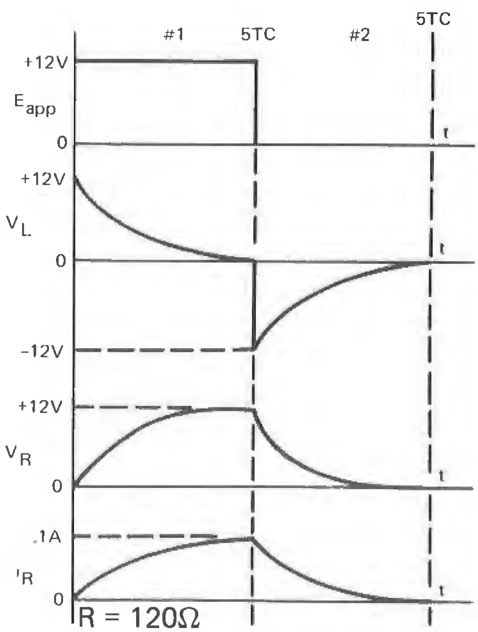
2. Plot the waveforms of $E_1$, $V_L$, $V_R$ and $i_R$ versus time for the circuit shown in figure 11-16, (*Electromechanisms/Devices*) for each value of R. Determine the time constant for each value of resistance. After five time constants, switch the relay to position number two and plot the discharge curves for each value of resistance.




$$\tau = \frac{L}{R} = \frac{3 \text{ Henrys}}{6 \text{ ohms}} = \mathbf{0.5\ sec}$$




$$\tau = \frac{L}{R} = \frac{3 \text{ Henrys}}{60 \text{ ohms}} = \mathbf{.05\ sec}$$




$$\tau = \frac{L}{R} = \frac{3 \text{ Henrys}}{120 \text{ ohms}} = \mathbf{.025\ sec}$$

**INTRODUCTION.** The student should learn how convection, conduction and radiation transfer thermal energy and how the thermal time constant is developed.

## TECHNICAL TERMS

**Time Constants.** The time required for an exponential quantity to change by an amount equal to 0.632 times the total change that will occur.

**Thermal Time Constant.** The time required for a thermal quantity to change by an amount equal to 0.632 times the total change that will occur.

**Mechanical Translational System.** A mechanical system which changes from one place or condition to another.

**Mass.** The quantity of matter in an object.

**Damping.** Reduction of energy in a mechanical or electrical system by absorption or radiation.

**Compliance (Deformation).** The ability to yield or flex.

**Prototype.** The first thing or being of its kind.

**Mechanical.** *Rotational:* A system by which energy is used or stored by the rotation of mechanical parts or devices.

**Fluids.** A system by which energy is used or stored by the use of pneumatic or hydraulic devices.

**Absolute Zero.** Lowest possible point on the scale of absolute temperature; the point at which all molecular activity ceases. Absolute zero is defined as -273.2°C, -459.7°F, or 0°K.

**Specific Heat.** The capacity of a material to be heated at a given temperature (expressed as calories per degree C per gram), compared to water, which has a specific heat of 1.

**Pressure.** Force per unit area. Measured in pounds per square inch.

**Volume.** The amount of space occupied in three dimensions.

**Insulator.** A material of such extremely low conductivity that, in effect, no current flows through it.

**Thermal Conductivity.** Ability of a substance to conduct heat.

**Conductor.** A bare or insulated wire or combination of wires suitable for carrying an electric current.

**Conduction.** The transmission of heat or electricity through or by means of a conductor.

**Convection.** The transmission of heat by the movement of heated particles as in air currents.

**Radiation.** The propagation of energy through space or through a material.

**Kinetic Energy.** Energy which a system possesses by virtue of its motion.

**Transistor.** A device made by attaching three or more wires to a small wafer of semiconducting material treated so that its properties are different at the point where each wire is attached. The three wires are called the emitter, base, and collector.

**Infared Rays.** Also called black light. Invisible waves longer than the longest visible red light waves but shorter than radio-frequency waves.

**Electromagnetism.** The magnetism produced by an electric current.

**Mutual Inductance.** The property that exists between two current-carrying conductors when the magnetic lines of force from one link with those of the other.

**Eddy Current.** Those currents induced in the body of a conducting mass by a variation in magnetic flux.

**Hysteresis Losses.** The power expended in a magnetic material as a result of magnetic hysteresis.

**Efficiency.** Ratio of the useful output of a physical quantity which may be stored, transferred, or transformed by a device, to the total input of the device.

**Heat Sink.** A device for dissipating the heat from a rectifier, transistor, or other heat-vulnerable component.

## MATHEMATICAL EXPRESSIONS

$$\tau = RC \text{ or } \tau = \frac{L}{R}$$

$$C_t = C_p m$$

$$R_t = \frac{1}{C_h A}$$

$$P = I^2 R$$

$$\Delta H = m \times C_p \times \Delta T$$

$$R_t = \frac{\ell}{\theta_c A}$$

$$\tau = R_t C_t$$

$$\%\ \text{eff.} = \frac{P_o}{P_{in}} \times 100$$

## MATERIALS

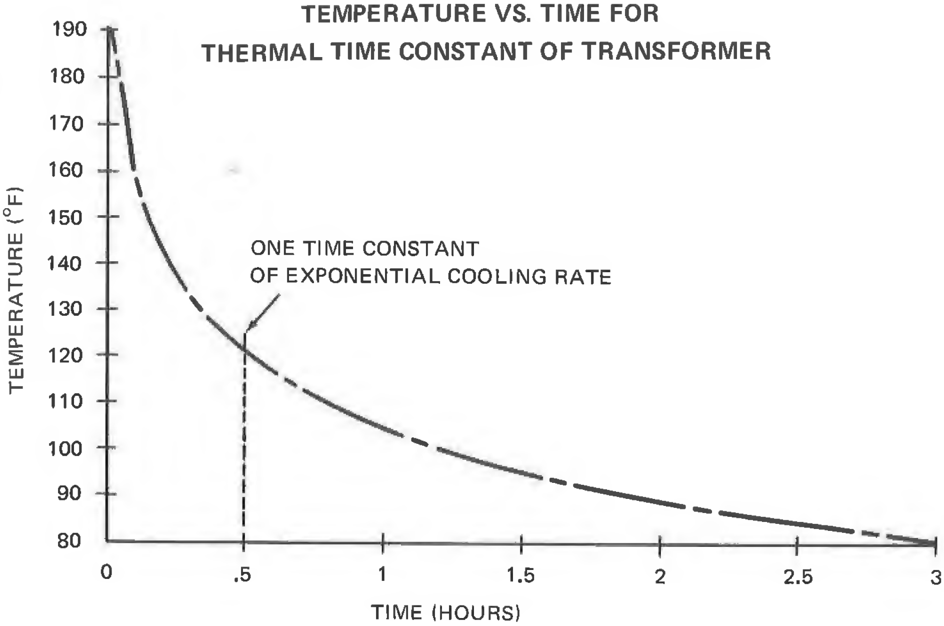
1 Output transformer, 100Ω primary: 3.2/8/16Ω secondary, 10W or equiv.
1 Thermocouple meter
1 AC motor
1 8″ X 6″ X 6″ wide cardboard box with insulation material
1 Mercury thermometer, 0-200°F optional
1 Variable transformer
1 Timer or watch with second hand

## DATA

| Temperature | Time |
|---|---|
| 190°F | 1:52 |
| 184° | 1:54 |
| 169° | 1:56 |
| 156° | 1:58 |
| 148° | 2:00 |
| 142° | 2:02 |
| 134° | 2:07 |
| 128° | 2:12 |
| 124° | 2:17 |
| 117° | 2:27 |
| 107° | 2:44 |
| 100° | 3:04 |
| 89° | 3:49 |
| 85° | 4:14 |
| 80° | 4:55 |

*Fig. 12-7 The Data Table*

**GRAPH**
**TEMPERATURE VS. TIME FOR THERMAL TIME CONSTANT OF TRANSFORMER**




**ANALYSIS.** The Graph, Temperature vs. Time for Thermal Time Constant of Transformer, displays the exponential cooling rate of the test transformer. One time constant is computed by knowing that the temperature decreases by 63.6% at one time constant. This constant (63.6%) times the maximum temperature is 121°F. This corresponds to 29.5 minutes on the graph. At fives time constants times the 29.5 minutes, the transformer should have reached the steady-state temperature.

From the graph, it is seen that the temperature is still 3-5°F above the steady-state value. This is partially due to the absorbed temperature of the box and insulating material.

**PRECAUTIONS.** It is important for the students to understand that electrical devices can be operated at maximum ratings (power, load, or temperature) for a short time without breakdown or failure. This experiment requires a similar condition as stated above, and therefore, the students should be cautioned not to overheat the transformer.

**PROBLEMS**

1. If a power transformer having a voltage step-up ratio of 1:6 is placed under load, what will be the approximate ratio of primary to secondary current?

   **6:1 ratio of primary to secondary current**

2. A 300-16 piece of aluminum whose specific heat is 0.22 BTU/lb–°F is heated from 70° to 100°F. How much heat did the aluminum absorb?

$$\Delta H = mC_p\Delta T$$

$$\Delta H = \frac{w}{g}(.22\ \text{BTU/lb–°F})(100°\text{F} - 70°\text{F})$$

$$= \frac{300\ \text{lbs}}{32.2\ \text{ft/sec}^2}(.22\ \text{BTU/lb–°F})(100°\text{F} - 70°\text{F}) = 2.05\ \text{BTU/°F}\ (30°\text{F})$$

$$= \mathbf{61.5\ BTUs}$$

3. A one-pound piece of iron at 212°F is dropped into one pound of water at 32°F. What is the temperature of the iron and water after the temperature of the mixture has had a chance to come to equilibrium? (The specific heat of iron is 0.12 BTU/lb-°F.)

Heat lost by iron

$\Delta H = mC_p\Delta T$ $m = 1$ lb-mass

$C_p = .12$ BTU/lb-°F

$\Delta T = 212°F - T°$

$\Delta H = 1$ lb-mass $(.12\text{BTU/lb-°F})(212°F - T°)$

$\Delta H = 25.5 - .12T$

Heat gained by water

$\Delta H = mC_p\Delta T$ $m = 1$ lb-mass

$C_p = 1$ BTU/lb-°F

$\Delta T = T - 32°F$

$\Delta H = (1\text{ lb-mass})(1\text{ BTU/lb-°F})(T° - 32°F)$

$\Delta H = T - 32$

Since no heat is lost: $25.5 - .12T = T - 32$; $57.5 = 1.12T$; **51.25°F = T**

# DC VERSUS AC OPERATION OF A SERIES MOTOR

**INTRODUCTION.** The student should learn how a universal motor operates with AC or DC input voltages and how inductive and capacitive reactance, impedance, and phase relationships are computed.

## TECHNICAL TERMS

**Universal Motor.** A series-wound motor designed to operate at approximately the same speed and output on direct current or on a single-phase alternating current of not more than 60 cycles per second and approximately the same rms voltage.

**Series Motor.** A motor in which the field and armature circuits are connected in series.

**Intermittent Duty.** Operation of a device for specified alternate intervals of load and no-load; load and rest; or load, no-load, and rest.

**Low Frequency (LF).** The band of frequencies extending from 30 to 300 kHz.

**Governor.** A motor attachment that automatically controls the speed at which the motor rotates.

**Noise.** Any unwanted disturbance within a dynamic electrical or mechanical system.

**Capacitance.** That property which permits the storage of electrically separated charges when potential differences exist between the conductors.

**Inductance.** The property which opposes any change in the existing current. Inductance is present only when the current is changing.

**Counter emf.** A voltage developed in an inductive circuit by an alternating or pulsating current. The polarity of this voltage is at every instant opposite that of the applied voltage.

**Impede.** To hinder the progress of.

**Inductive Reactance ($X_L$).** The opposition to the flow of alternating or pulsating current by the inductance of a circuit. It is measured in ohms.

**Effective Current.** That value of alternating current which will give the same heating effect as the corresponding value of direct current. For the sine-wave alternating currents, the effective value is 0.707 times the peak value.

**Capacitive Reactance ($X_C$).** The impedance a capacitor offers to AC or pulsating DC, measured in ohms.

**Impedance.** The total opposition (resistance and reactance) a circuit offers to the flow of alternating current, measured in ohms.

**Phase Difference.** The time in electrical degrees by which one wave leads or lags another.

**Polar Diagram.** A diagram in which the magnitude of a quantity is shown by polar coordinates.

**Real Power.** The component of apparent power that represents true work in an AC circuit. It is expressed in watts and is equal to the apparent power times the power factor.

**Apparent Power.** The product of voltage and current of a single-phase circuit in which the two reach their peaks at different times.

**Power Factor.** Ratio of the actual power of an alternating or pulsating current, as measured by a wattmeter, to the apparent power, as indicated by an ammeter and voltmeter.

**Reactive Power.** Also called wattless power. The reactive voltage times the current, or the voltage times the reactive current, in an AC circuit. Unit of measurement is the VAR, (Volt Ampere Reactive).

## MATHEMATICAL EXPRESSIONS

$$\%\text{ speed regulation} = \frac{\omega_{NL} - \omega_{FL}}{\omega_{FL}} \times 100$$

$$\text{Cemf} = \frac{2\phi C\omega}{60 \times 10^{-8}} \qquad \text{Cemf} = E_{in} - I_a R_a$$

$$I_a = \frac{E - \text{Cemf}}{R} \qquad P = I_a^2 R_a$$

$$P = (E - \text{Cemf})\, I_a \qquad I = \frac{V_L}{X_L}$$

$$X_L = 2\pi f L = \omega L \qquad X_C = \frac{1}{2\pi f C} = \frac{1}{\omega C}$$

$$E = V_R + V_C + V_L \qquad E = V_R + jV_L - jV_C$$

$$\text{pf} = \cos\theta = \frac{P_R}{P_a} \qquad \theta = \arc\tan \frac{X_L}{R}$$

## MATERIALS

1 Dynamometer
1 Instrument panel which will indicate watts, voltage, current and power factor
1 Universal motor
1 Variable transformer
1 DC power supply with voltage and current meters
Appropriate couplings and motor mounts as needed

## DATA

DC windings resistance 3.532 Ω

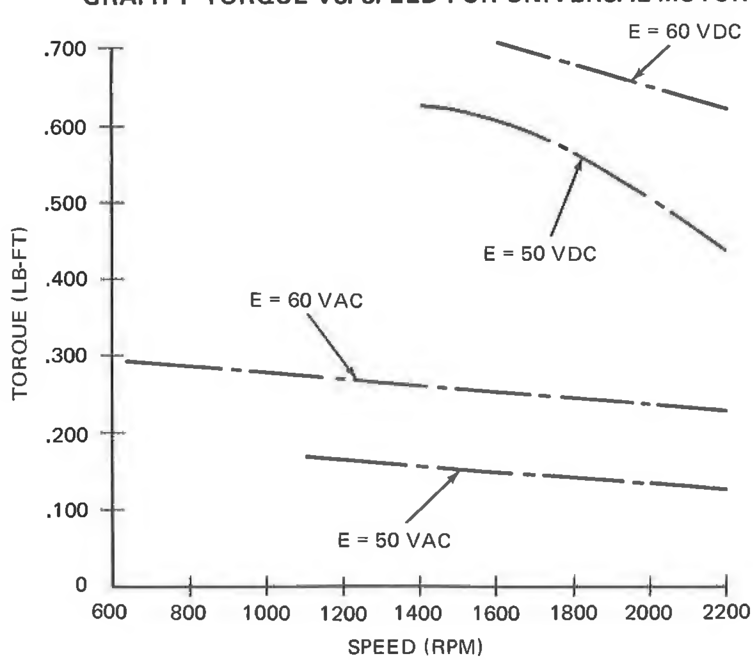
| Voltage | Force oz. | Torque lb-ft | Speed RPM | Current amps | $P_{in}$ W | $P_{out}$ W | Efficiency |
|---|---|---|---|---|---|---|---|
| 50 | 21 | .437 | 2200 | 6.8 | 163 | 136.5 | 83.8% |
| 50 | 24 | .50 | 2000 | 7.4 | 193 | 142 | 73.6% |
| 50 | 28 | .584 | 1800 | 7.6 | 204 | 149 | 73.0% |
| 50 | 29 | .604 | 1600 | 8 | 226 | 137 | 60.7% |
| 50 | 30 | .625 | 1400 | 8.2 | 237 | 125 | 52.8% |
| 60 | 30 | .625 | 2200 | 8.2 | 238 | 195 | 82 % |
| 60 | 31 | .647 | 2000 | 8.4 | 248 | 183 | 73.9% |
| 60 | 32 | .667 | 1800 | 8.8 | 273 | 170 | 62.3% |
| 60 | 34 | .709 | 1600 | 9.2 | 300 | 161 | 53.7% |

*Fig. 13-12 The Data Table*

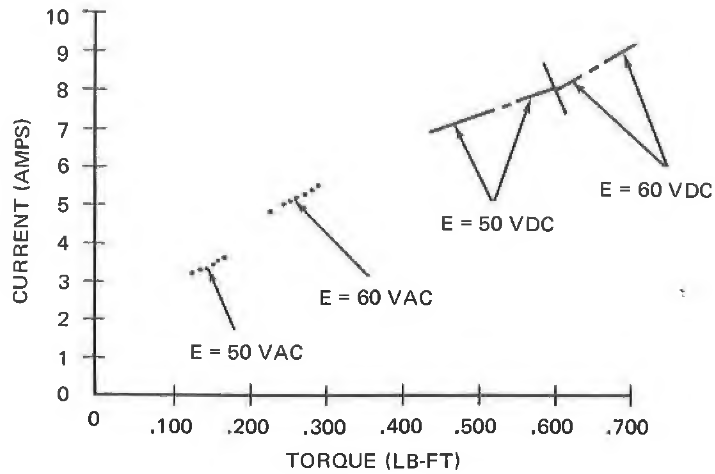
| Voltage | Force | Torque | Speed | Current | Watts | $P_{out}$ | Power Rate | Eff. |
|---|---|---|---|---|---|---|---|---|
| 50 | 6.0 | .125 | 2200 | 3.25 | 120 | 39.1 | .74 | 32.6 % |
| 50 | 6.25 | .13 | 2100 | 3.26 | 110 | 38.8 | .73 | 35.3 |
| 50 | 6.50 | .135 | 2000 | 3.3 | 112 | 38.4 | .72 | 34.3 |
| 50 | 6.75 | .140 | 1900 | 3.26 | 115 | 37.8 | .72 | 32.9 |
| 50 | 7 | .146 | 1800 | 3.35 | 115 | 37.3 | .7 | 32.4 |
| 50 | 7.25 | .151 | 1700 | 3.4 | 115 | 36.5 | .7 | 31.7 |
| 50 | 7.25 | .151 | 1600 | 3.5 | 115 | 34.3 | .7 | 29.8 |
| 50 | 7.5 | .156 | 1500 | 3.5 | 115 | 33.2 | .68 | 28.9 |
| 50 | 7.75 | .161 | 1400 | 3.55 | 115 | 32.1 | .68 | 27.9 |
| 50 | 7.75 | .161 | 1300 | 3.6 | 115 | 29.8 | .67 | 25.8 |
| 50 | 8.0 | .167 | 1200 | 3.6 | 115 | 28.4 | .66 | 24.7 |
| 50 | 8.0 | .167 | 1100 | 3.6 | 110 | 26.1 | .65 | 23.7 |
| 60 | 11.0 | .229 | 2200 | 4.8 | 180 | 71.5 | .77 | 39.7 |
| 60 | 11.0 | .229 | 2100 | 4.85 | 180 | 68.4 | .76 | 38.0 |
| 60 | 11.5 | .239 | 2000 | 4.8 | 190 | 67.9 | .75 | 35.8 |
| 60 | 12.0 | .250 | 1800 | 5.0 | 190 | 64.0 | .74 | 33.7 |
| 60 | 12.1 | .252 | 1600 | 5.1 | 190 | 57.3 | .73 | 30.1 |
| 60 | 12.5 | .261 | 1400 | 5.15 | 190 | 51.9 | .72 | 27.3 |
| 60 | 13.0 | .271 | 1200 | 5.2 | 190 | 46.2 | .69 | 24.4 |
| 60 | 13.5 | .281 | 1000 | 5.3 | 190 | 40.0 | .7 | 21.0 |
| 60 | 14.0 | .292 | 800 | 5.4 | 190 | 33.2 | .69 | 17.5 |
| 60 | 14.0 | .292 | 600 | 5.5 | 190 | 24.9 | .65 | 13.1 |

*Fig. 13-13 The Data Table*

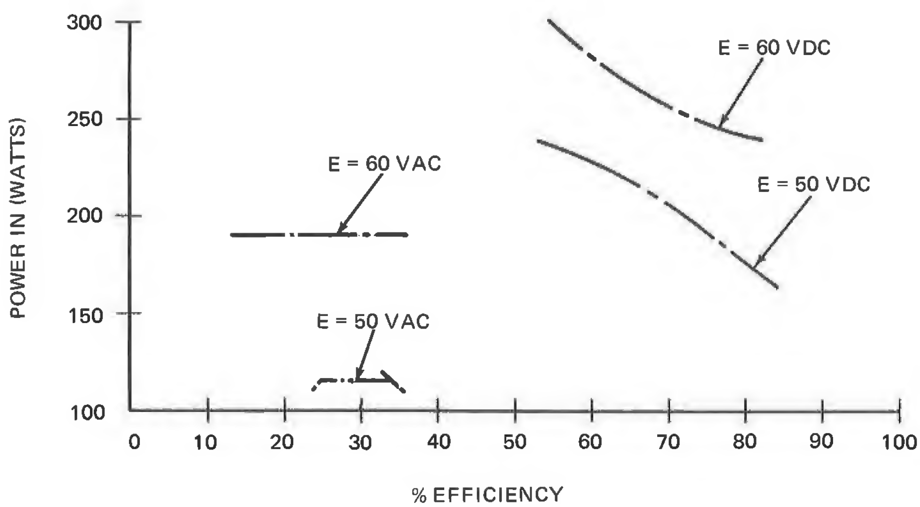
**GRAPH 1 TORQUE VS. SPEED FOR UNIVERSAL MOTOR**



GRAPH 2 CURRENT VS. TORQUE FOR UNIVERSAL MOTOR



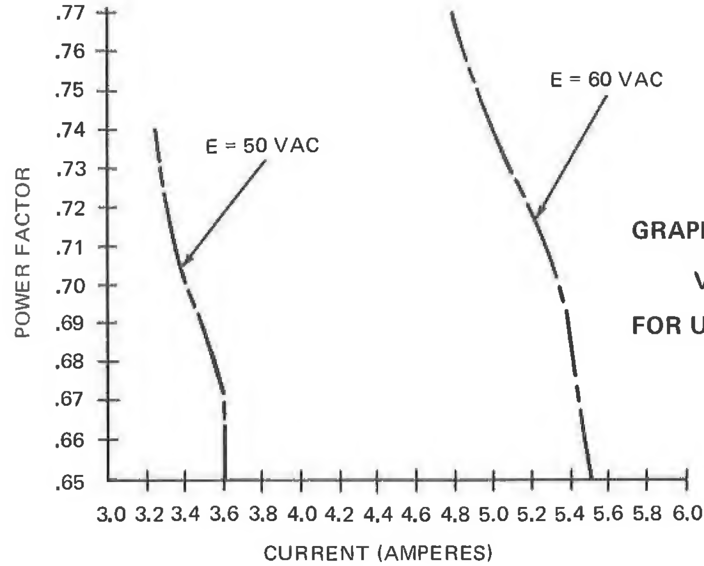

GRAPH 3 POWER IN VS. EFFICIENCY FOR UNIVERSAL MOTOR




**ANALYSIS.** Graph 1 shows that when the universal motor is operated with a DC input, a greater torque is produced than when operated with AC.

Graph 2 shows that the current increases linearly with torque for both AC and DC operation. The DC operation resulted in a larger torque and current.

Graph 3 shows that the efficiency of the universal motor when operated on DC is far greater than when operated with AC. From this graph, it is easily seen that the universal motor is much more efficient operating on DC than on AC. The reason is that the DC motor does not have the losses due to hysteresis and eddy current. Also the opposition to flow in the DC motor is much less because it does not have the effects of the reactive elements.




**GRAPH 4 POWER FACTOR VS. CURRENT FOR UNIVERSAL MOTOR**

## PROBLEMS

1. What is the inductive reactance of a pure inductance which allows a five amp current to flow when it is connected across a 117 V AC source?

$$X_L = \frac{117\text{ V AC}}{5\text{ amps}} = \mathbf{23.4\ \Omega}$$

2. At what frequency will the reactance of a 640 $\mu$H coil equal that of a 800 $\mu\mu$F capacitor?

$$X_L = X_C$$

$$2\pi fL = \frac{1}{2\pi fC}$$

$$(6.28)\,f\,(640\mu H) = \frac{1}{(6.28)\,f\,(800\mu\mu F)}$$

$$f^2 = \frac{1}{20.17\mu\mu}$$

$$f = \sqrt{.0496\text{ mm}}$$

$$f = 222\text{ kHz}$$

3. What is the total impedance at 60 Hertz of a series circuit consisting of a 0.5 Henry inductor with a 200 ohm resistance and a 30$\mu$F capacitor?

$$X_L = 2\pi fL = 6.28(60Hz)(.5H) = 188.40\ \Omega$$

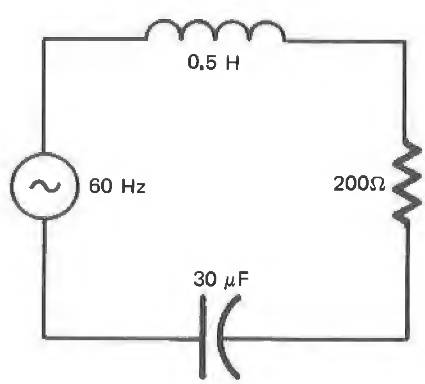
$$X_C = \frac{1}{2\pi fC} = \frac{1}{6.28\ (60Hz)(30\mu F)} = \mathbf{91\ \Omega}$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$= \sqrt{(200\Omega)^2 + (188.4\Omega - 91\Omega)^2}$$

$$Z = \sqrt{40\text{ k}\Omega + 9.5\text{ k}\Omega}$$

$$= \sqrt{49.5\text{ k}\Omega} = \mathbf{222\ \Omega}$$



# instructor's guide 14 A C VERSUS DC RELAY OPERATION

**INTRODUCTION.** The student should learn: how a relay operates, contact materials and ratings, and the power used in AC and DC operation.

## TECHNICAL TERMS

**Electronic Tubes.** An electron device in which the electrons move through a vacuum or gaseous medium within a gas-tight envelope.

**Photoelectric Cell.** Also called a photocell. A light-sensitive cell which translates variations in light into corresponding variations in electrical signals.

**Thermocouple.** A pair of dissimilar conductors joined together so that an electromotive force is developed by the thermoelectric effects when the two junctions at opposite ends are at different temperatures.

**Chatter (Bounce).** The prolonged, undesirable vibration of electrical contacts when opened or closed.

**Welding.** The process of joining two metals, usually by the application of heat.

**Arcing.** The luminous discharge of electricity.

**Conductivity.** The ability of a material to transfer energy (electrical, thermal, or acoustical) from one location to another.

**Melting Temperature.** That temperature which causes a material to change from the solid state into the liquid state.

**Vaporization Temperature.** That temperature which causes a material to change from the liquid to the gaseous state.

**Mechanical Wear.** Impairment or loss from use, friction, etc.

**Micro-Switch.** A small mechanical or electrical device that completes or breaks the path of electric current when activated with a minimal amount of force.

**Vacuum Switch.** A switch in which the contacts are enclosed in an evacuated bulb, usually to minimize sparking.

**Shading Coil.** An additional coil in an AC relay which minimizes armature chatter and hum.

**Residual Magnetism.** The magnetism which remains in the core of an electromagnet after the operating circuit has been opened.

**Electrolytic Corrosion.** Gradual chemical or electrochemical destruction of a metal by atmosphere, moisture, gases or other agents.

**Inductive Reactance ($X_L$).** The opposition to the flow of alternating or pulsating current by the inductance of a circuit, measured in ohms.

**Impedance (Z).** The total opposition (resistance and reactance) a circuit offers to the flow of alternating current, measured in ohms.

**Phase Angle ($\theta$).** The angle in degrees or radians which gives the relationship in position between two alternating quantities.

**Apparent Power.** The product of the voltage and current of a single-phase circuit in which the two reach their peaks at different times.

**Real Power.** The component of apparent power that represents true work in an AC circuit, expressed in watts.

**Reactive Power.** The reactive voltage times the current, or the voltage times the reactive current in an AC circuit, measured in VAR, (volt-ampere-reactive).

**Power Factor.** Ratio of the actual power of an alternating or pulsating current, as measured by a wattmeter, to the apparent power, as indicated by an ammeter and voltmeter.

## MATHEMATICAL EXPRESSIONS

$$X_L = 2\pi f L$$

$$I = \frac{E}{Z}$$

$$P_R = I^2 R$$

$$V_L = X_L \frac{E}{|Z|} \angle 90° - \theta$$

$$Z = R + jX_L$$

$$P_a = EI$$

$$V_R = RI_R = R \frac{E}{|Z|} \angle -\theta$$

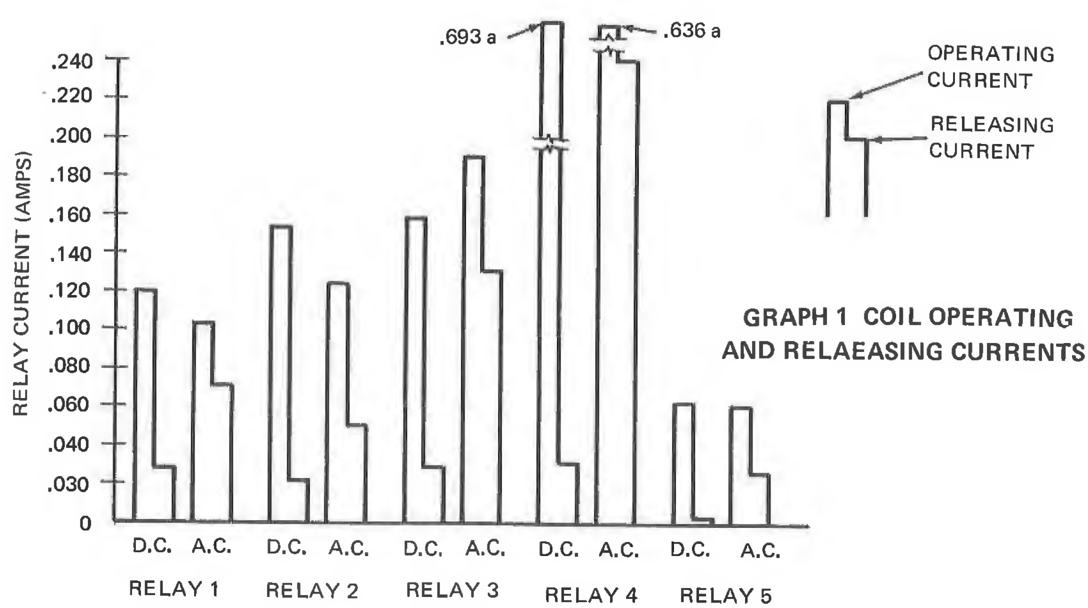
## MATERIALS

5 AC relays, various sizes and shapes
1 Variable transformer
1 DC power supply
2 VOMs
1 AC ammeter

## DATA

| Operating Power | | |
|---|---|---|
| Relay | DC | AC |
| #1 | 2.74 W | 2.02 W |
| #2 | 5.37 | 3.54 |
| #3 | .650 | .940 |
| #4 | 4.50 | 3.80 |
| #5 | 1.19 | 1.15 |

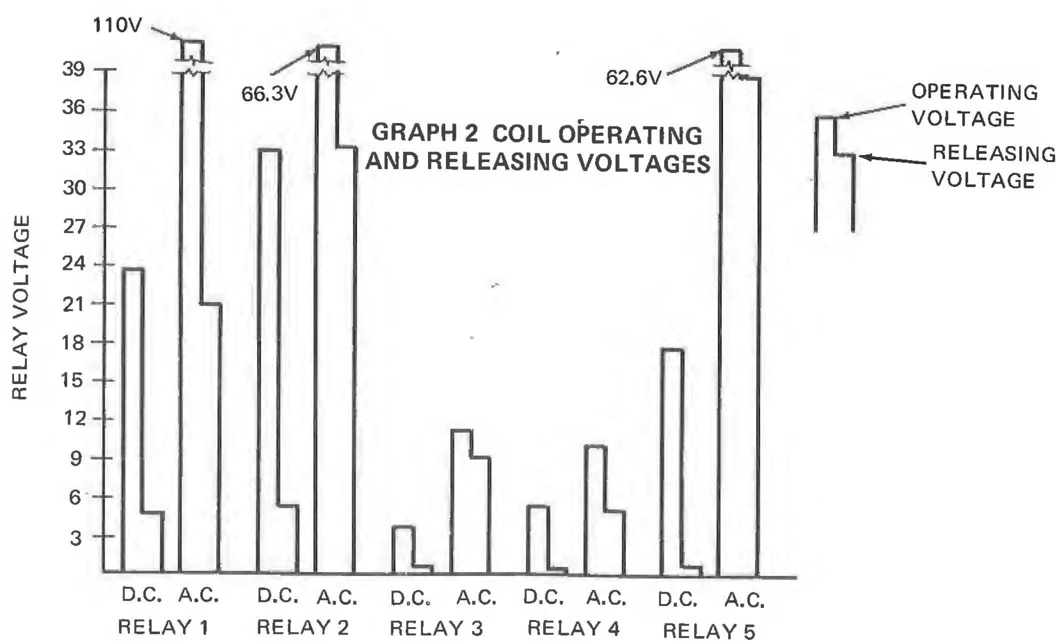
*Fig. 14-13*




**GRAPH 1 COIL OPERATING AND RELAEASING CURRENTS**

| Relay | Trial | DC INPUT Operating Current | DC INPUT Operating Volt | DC INPUT Releasing Current | DC INPUT Releasing Volt | AC INPUT Operating Current | AC INPUT Operating Volt | AC INPUT Releasing Current | AC INPUT Releasing Volt |
|---|---|---|---|---|---|---|---|---|---|
| #1 | #1 | .11 A | 23 | 28 mA | 4.7 | 102 mA | 110 | 71 mA | 22 |
| | #2 | .12 | 24 | 27 | 4.8 | 105 | 110 | 72 | 21 |
| | #3 | .13 | 24 | 30 | 5.1 | 104 | 111 | 70 | 20 |
| | Average | .12 | 23.7 | 28.3 | 4.87 | 103.7 | 110.3 | 71 | 21 |
| #2 | #1 | .15 | 30 | 21 | 5 | 125 | 67 | 49 | 32 |
| | #2 | .155 | 35 | 24 | 6 | 120 | 65 | 49 | 33 |
| | #3 | .155 | 34 | 21 | 5 | 126 | 67 | 53 | 35 |
| | Average | .153 | 33 | 22 | 5.3 | 123.7 | 66.3 | 50.3 | 33.3 |
| #3 | #1 | .16 | 3.8 | 28 | .6 | 195 | 11.7 | 140 | 9.6 |
| | #2 | .155 | 3.6 | 29 | .7 | 190 | 10.9 | 130 | 9 |
| | #3 | .16 | 3.7 | 29 | .7 | 185 | 11 | 125 | 9 |
| | Average | .158 | 3.7 | 28.7 | .66 | 190 | 11.2 | 131.7 | 9.2 |
| #4 | #1 | .68 | 5.1 | 32 | .3 | 620 | 10.5 | 260 | 5 |
| | #2 | .72 | 5.5 | 31 | .28 | 660 | 10.6 | 240 | 5 |
| | #3 | .68 | 5.2 | 31 | .26 | 630 | 10 | 220 | 4.8 |
| | Average | .693 | 5.27 | 31.3 | .28 | 636.6 | 10.3 | 240 | 4.93 |
| #5 | #1 | 63 mA | 18 | 2.5 | .9 | 62 | 63 | 26 | 39 |
| | #2 | 62 | 18 | 2.8 | .95 | 61 | 62 | 26 | 39 |
| | #3 | 61 | 17.5 | 2.7 | 1.0 | 62 | 63 | 26 | 39 |
| | Average | 62 | 17.83 | 2.66 | .95 | 61.6 | 62.6 | 26 | 39 |

*Fig. 14-14 Data Table of Operating and Releasing Characteristics of a Relay*



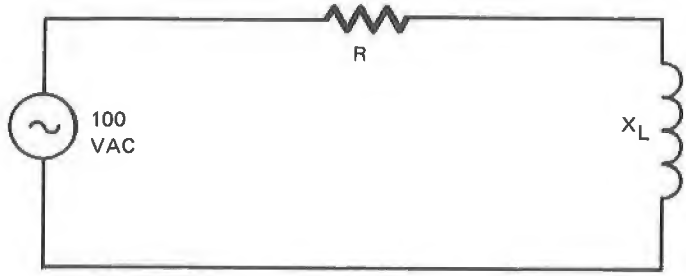
**ANALYSIS.** Graph 1 shows that a greater DC current is needed to operate the relays in all but one relay. Current in a DC circuit is computed by E/R. In an AC circuit the current is equal to E/Z, where the impedance (Z) is computed from $R + jX_L$. This equation shows that the current in a circuit operating with AC must be less than the same circuit acting under DC.

Graph 2 shows that the relay operating voltage for DC is much less than the AC voltage. The greater AC voltage is needed so that eddy currents and hysteresis losses are overcome.

The operating power of a DC circuit is computed by EI. The power of an AC circuit is EI cos $\theta$, where $\theta$ is the phase angle between voltage and current. Cos $\theta$ is never greater than one, so the AC power of a relay, when operated at equal voltages, will always be less than the DC power.

**PROBLEMS**

1. Draw a schematic diagram of a circuit with $X_L$ and R in series across a 100 volt source. Calculate Z, I, IR, $IX_L$ and $\theta$ for the following values: a) 100 ohm - R 1 ohm - $X_L$ b) 1 ohm - R 100 ohm - $X_L$ c) 50 ohm - R 50 ohm - $X_L$




a) **$R = 100\Omega$ $X_L = 1\Omega$**

$Z = R + jX_L$

$Z = 100\Omega + j1\Omega$

$\mathbf{Z \simeq 100\Omega \angle 0°}$

$\theta = \angle \mathbf{0°}$

$I = \frac{E}{Z}$

$I = \frac{100\text{ VAC}}{100\ \Omega}$

**I = 1 amp**

IR = 1 amp$(100\Omega)$

**IR = 100 volts**

$IX_L$ = 1 amp$(1\Omega)$

**$IX_L$ = 1 volt**

b) **$R = 1\Omega$ $X_L = 100\Omega$**

$Z = R + jX_L$

$Z = 1\Omega + j100\Omega$

$\mathbf{Z = 100\Omega \angle 90°}$

$\theta = \angle \mathbf{90°}$

$I = \frac{E}{Z}$

$I = \frac{100\text{ VAC}}{100\ \Omega}$

**I = 1 amp**

IR = 1 amp$(1\Omega)$

**IR = 1 volt**

$IX_L$ = 1 amp$(100\Omega)$

**$IX_L$ = 100 volts**

c) **$R = 50\Omega$ $X_L = 50\Omega$**

$Z = R + jX_L$

$Z = 50\Omega + j50\Omega$

$\mathbf{Z \simeq 70.5\Omega \angle 45°}$

$\theta = \angle \mathbf{45°}$

$I = \frac{E}{Z}$

$I = \frac{100\text{ volts}}{70.5\ \Omega}$

**I = 1.418 amps**

IR = (1.418 amps)$(50\Omega)$

**IR = 70.9 volts**

$IX_L$ = (1.418 amps)$(50\Omega)$

**$IX_L$ = 70.9 volts**

2. Calculate the apparent power, real power, and reactive power from the values used in problem 1.

a) $P_a$ = EI = (100 volts)(1 amp) = **100 volt-amps**

$P_R = I^2R$ = (1 amp)$^2$ 100 $\Omega$ = **100 watts**

$P_q = IV_L = (1 \text{ amp})(1 \text{ volt}) = \mathbf{1\ VAR}$

b) $P_a = EI = (100 \text{ volts})(1 \text{ amp}) = \mathbf{100\ volt\text{-}amps}$

$P_R = I^2R = (1 \text{ amp})^2 1\ \Omega = \mathbf{1\ watt}$

$P_q = IV_L = (1 \text{ amp})(100 \text{ volts}) = \mathbf{100\ VAR}$

c) $P_a = EI = (100 \text{ volts})(1.418 \text{ amps}) = \mathbf{141.8\ volt\text{-}amps}$

$P_R = I^2R = (1.418 \text{ amps})^2\ 50\ \Omega = \mathbf{100.5\ watts}$

$P_q = IV_L = (1.418 \text{ amps})(70.9 \text{ volts}) = \mathbf{100.6\ VAR}$

**INTRODUCTION.** The student should learn how resonance occurs in electrical, mechanical, and physical systems and how the resonant frequency is computed and measured.

## TECHNICAL TERMS

**Natural Frequency.** The frequency at which a body will oscillate if disturbed from its equilibrium position.

**Periodicity.** Appearing or recurring at regular intervals.

**Resonance.** A circuit condition whereby the inductive and capacitive reactance components of a circuit have been balanced. In usual circuits, resonance can be obtained for only a comparatively narrow frequency band or range.

**Inductive Reactance ($X_L$).** The opposition to the flow of alternating or pulsating DC, measured in ohms.

**Impedance.** The total opposition (resistance and reactance) a circuit offers to the flow of alternating current. It is measured in ohms.

**Transient Ringing.** A momentary oscillation which occurs in a circuit during switching or circuit parameter change.

**Tuned Circuit.** A circuit consisting of inductance and capacitance which can be adjusted for resonance at the desired frequency.

**Tuned Filter.** A resonant circuit connected between two circuits to prevent signals of its own resonant frequency from passing.

**Oscillator.** An electronic device which generates an alternating current at a frequency determined by the values of certain constants in its circuits.

**Constructive Interference.** When two waves come together such that crest meets crest and trough meets trough, the resulting composite wave has an amplitude *greater* than that of the original waves.

**Destructive Interference.** When crest meets trough and trough meets crest, the composite wave has an amplitude *less* than that of either of the original waves.

**Crest.** The maximum absolute value of a function.

**Superposition.** When a number of voltages are applied to the network simultaneously, the current that flows is the sum of the component currents that would flow if the same voltages had acted individually. Likewise, the potential difference that exists between any two points is the component potential difference that would exist there under the same conditions.

**Nodes.** Also called nodal point. In a standing wave, a point, line or surface where some characteristic of the wave field has essentially zero amplitude.

**Fundamental Frequency.** The principal component of a wave; i.e., the component with the lowest frequency or greatest amplitude. It is usually taken as a reference.

**Overtones.** In a complex sound, a physical component having a higher frequency than the basic frequency.

**Transducer.** A device which converts one form of energy (electrical, thermal, acoustical) into a proportional output of another form of energy (mechanical, pneumatic, hydraulic).

**Piezoelectric Transducer.** Also called ceramic or crystal transducer. A transducer that depends for its operation on the interaction between the electric charge and the deformation of certain asymmetric crystals having piezoelectric properties.

**Electromagnetic.** The magnetism produced by an electric current.

**Vibrating-Reed Meter.** A frequency meter consisting of a row of steel reeds, each having a different natural frequency. All are excited by an electromagnet fed with the alternating current whose frequency is to be measured. The reed whose frequency corresponds most nearly with that of the current vibrates, and the frequency is read on a scale beside the row of reeds.

## MATHEMATICAL EXPRESSIONS

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \qquad X_L = 2\pi fL$$

$$X_C = \frac{1}{2\pi fC} \qquad f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$L = \frac{1}{4\pi^2 f_r^{\,2} C} \qquad C = \frac{1}{4\pi^2 f_r^{\,2} L}$$

$$f_1 = \frac{\nu}{\lambda} = \frac{\nu}{2L}$$

## MATERIALS

1 DC power supply
1 DC motor, 28V, 7000 RPM, 0.7 amperes
1 Motor bracket
5 Small C-clamps
5 Pieces of piano wire, .062" dia., 4-1/2, 5-1/2, 6-1/2, 9-1/2, 12-1/2"
1 Stroboscope
1 Breadboard
1 Collar and set screw
1 1000 Ω resistor
1 500 Ω resistor
1 1 μF capacitor
1 1 Henry inductor
1 Audio oscillator
1 VOM

**SUGGESTIONS.** To obtain the best results when running the second portion of this experiment, it is advisable to maintain a constant amplitude output from the audio oscillator. The use of an oscilloscope can accomplish two functions: (1) a constant amplitude can be maintained by adjusting the amplitude control on the oscillator, and (2) the changing frequency can be seen.

## DATA

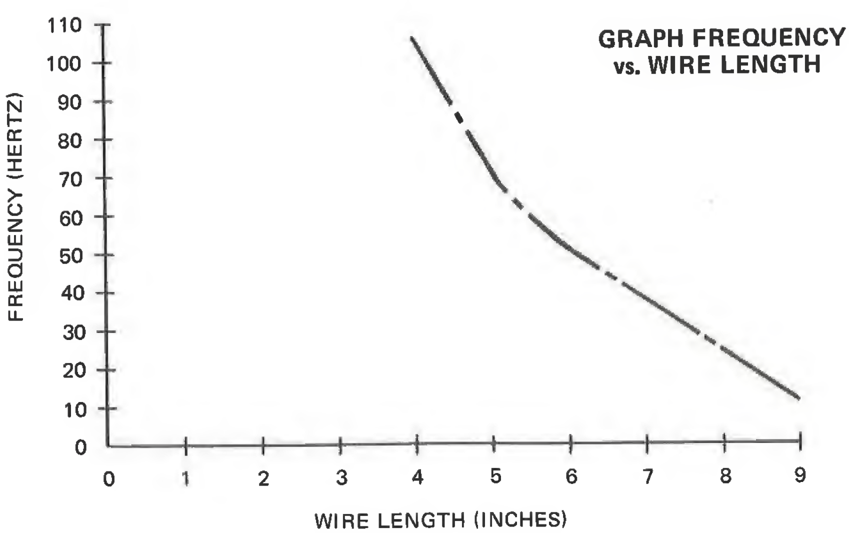
| Wire Length | Speed of Vibrations, RPM | Frequency, CPS |
|---|---|---|
| 4 | 6400 | 106.6 |
| 5 | 4300 | 71.6 |
| 6 | 3000 | 50 |
| 9 | 650 | 10.8 |

*Fig. 15-11 Data Table I*

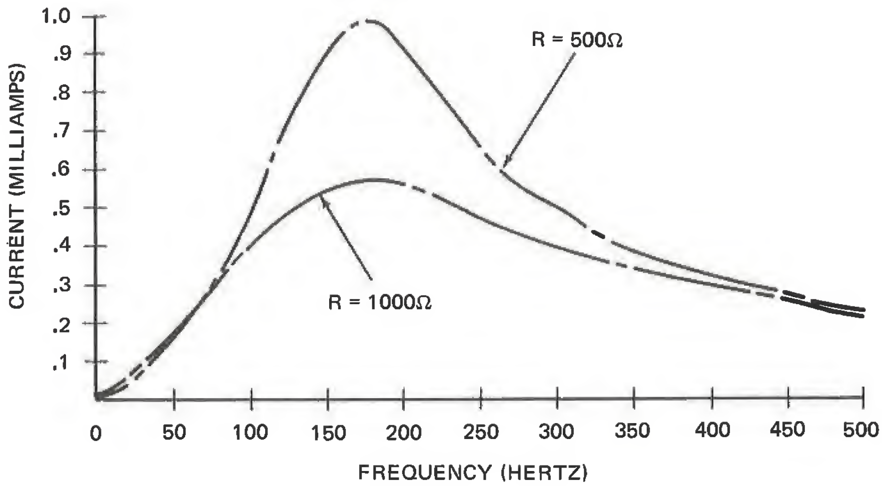
$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{.159}{\sqrt{1H\,(1\mu F)}} = \frac{.159}{.001}$$ = 159 Hertz Calculated Frequency.

| Frequency | Voltage | | Current | |
|---|---|---|---|---|
| (Hertz) | R = 1k Ω | R = 500 Ω | R = 1k Ω | R = 500 Ω |
| 20 | .05 V | .02 V | .05 mA | .04 mA |
| 40 | .13 | .06 | .13 | .12 |
| 60 | .22 | .11 | .22 | .22 |
| 80 | .31 | .17 | .31 | .34 |
| 100 | .40 | .25 | .40 | .50 |
| 120 | .47 | .34 | .47 | .68 |
| 140 | .52 | .42 | .52 | .84 |
| 160 | .56 | .48 | .56 | .96 |
| 180 | .56 | .49 | .56 | .98 |
| 200 | .55 | .45 | .55 | .90 |
| 220 | .52 | .40 | .52 | .80 |
| 240 | .48 | .35 | .48 | .70 |
| 260 | .45 | .30 | .45 | .60 |
| 280 | .42 | .27 | .42 | .54 |
| 300 | .40 | .25 | .40 | .50 |
| 320 | .37 | .22 | .37 | .50 |
| 340 | .35 | .20 | .35 | .40 |
| 360 | .33 | .185 | .33 | .37 |
| 380 | .31 | .17 | .31 | .34 |
| 400 | .29 | .16 | .29 | .32 |
| 420 | .28 | .15 | .28 | .30 |
| 440 | .27 | .14 | .27 | .28 |
| 460 | .25 | .13 | .25 | .26 |
| 480 | .23 | .12 | .23 | .24 |
| 500 | .22 | .115 | .22 | .23 |

*FIG. 15-13 DATA TABLE II*



**GRAPH 2 FREQUENCY VS. CURRENT**




**ANALYSIS.** Graph 1 shows that as the wire length increases, the frequency of resonance decreases. This inverse proportionality is best examined by the playing of a guitar or piano. The shorter the wire length, the higher the frequency of vibration.

Graph 2 shows that the LCR circuit is resonant at approximately 180 Hertz. The computed resonant frequency is 159 Hertz. The difference between the measured and computed values is the result of the circuit components not being exactly 1 Henry, 1 $\mu$F, and 1000 or 500 ohms.

From Graph 2, when the resistance was decreased by 1/2, the current correspondingly increased by a factor of two. Using Ohm's Law

$$I = \frac{E}{R_1} \qquad 2I = \frac{E}{1/2\ R_1}$$

**PROBLEMS**

1. What is the frequency at resonance of a series circuit having an inductance of 100 $\mu$H if the capacitor is adjusted to 159 $\mu$F?

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{6.28\sqrt{(100\mu H)\ (159\mu F)}} = \frac{.159}{\sqrt{.0159\mu}} = \frac{.159}{.126m} = \mathbf{1.26\ kHz}$$

2. How much inductance is required in a series circuit having a capacitance of 250 $\mu\mu$F to produce resonance with a 1000 kHz signal input?

$$L = \frac{25{,}300}{f_r^2 C} = \frac{25{,}300}{(1000KC)^2(250\mu\mu F)} = \frac{25{,}300}{250} = 101.2\ H$$

3. To what value must a capacitor in a series circuit be adjusted to produce resonance at 300 kHz if the inductance of the circuit is 400 $\mu$H?

$$C = \frac{25{,}300}{f_r^2 L} = \frac{25{,}300}{(300k)^2(400\mu H)} = \frac{25{,}300}{36\ m} = 703\ \mu\ F$$

## EQUIPMENT LIST

The following list shows recommended quantities and specifications for equipment sufficient to handle a 10 setup, 20 student laboratory.

10 Student Component Kits (Electrical) including:

- 1 10-watt output transformer 100Ω 4/8/16Ω
- 1 Resistor 15Ω 2W
- 1 Resistor 1kΩ 25W
- 1 Resistor 5kΩ 2W
- 1 Resistor 10kΩ 2W
- 1 Resistor 100kΩ 2W
- 1 Resistor 500Ω 25W
- 1 Capacitor 1 $\mu$F 600 VDC
- 1 Capacitor 2 $\mu$F 600 VDC
- 1 Inductor 1H Q = 10 at 60 Hz
- 1 Switch SPDT
- 2 Bar magnets 1″ x 6″ x 1/4″
- 1 Magnetic compass
- 1 Shaker with iron filings

10 Variable transformer

0 - 130-volt output
115V, 60 Hz input
2 amp fused

10 Student Component Kits (Mechanical) including:

- 1 Breadboard 8″ x 16″ x 1/4″ with legs
- 1 Motor shaft coupling
- 1 Ring stand with clamps
- 1 Pulley 2″ OD 1/4″ bore hub
- 1 Pulley 1-1/2″ OD 1/4″ bore hub
- 5 "C" clamps 2″ adjustment
- 2 Piano wire 0.062″ dia. 24″ long
- 1 Spring stock 6″ x 1/8″ OD

10 Spring Balance

0 - 21b

10 Mercury Thermometer

32° - 212°F

10 DC Relay

115V

Open frame construction with coil spring on armature

10 Sine/Square Wave Generator

*Frequency range*
5 Hz - 600 kHz
*Output level*
Sine wave: 10V into 600 ohms
Square wave: 10V p-p
*Amplitude variation*
±1 db band-band
*Distortion*
Less than 1% 5 kHz - 600 kHz
*Rise time*
Less than 0.2 μsec
*Calibration accuracy*
±2%
*Dimensions*
11-1/2" x 9" x 11-1/4"
*Weight*
24 lbs

10 Oscilloscopes

*Vertical amplifier*
Band width: DC to 10 MHz, 3 db down
Rise time: 35 ns
Deflection factor: 50-200, 000 mV/cm, in 14 steps
Input impedance: 1 megohm in parallel with 30 pf
*Horizontal deflection*
External
Band width: 10 Hz to 0.5 MHz, 3 db
Deflection factor: Continuously adjustable from 300 mV to 50V
Internal
Time base: 100 ns to 0.5 sec
Time base adjustment: Cal. steps in 1, 2, 5 seq.
*Triggering*
External trigger input impedance: 0.1 megohm in parallel with 25 pF max.
Maximum external trigger input: 400V DC to peak AC
*CRT*
Diameter 4"

20 Multipurpose Meter

*DC volts*
Ranges: 0 - 1, 3, 10, 30, 100, 300 and 1000 full scale
Input resistance: 15 megohms shunted by 14 pF
Accuracy: ±3% full scale

10 Thermocouple meters

Three ranges
0 - 50 mV
0 - 500 mV
0 - 1000 mV

10 Dynamometer with Power Supply

Hysteresis type
0 - 100 in.-oz
0 - 15000 RPM
Base plate 7 x 13-1/2 inches

10 Electronic Stroboscope, Flashing Light Source (Portable) used to measure the speed of fast moving devices

*Power required*
105 to 125 volts
*Flashing-rate range*
110 to 25,000 flashes per minute
Three direct-reading scales
110 to 690
670 to 4170
4000 to 25,000
*Accuracy*
±1% of dial reading on middle range
*Mounting*
Flip-tilt case
*Dimensions*
10-5/8 W x 6-5/8 H x 6-1/8 D inches

10 Strip chart recorder

Dual channel

50 AC relays

115 VAC 60 Hz
DPST contacts
5 different frame constructions
Core approx. 1/2" dia. x 1" long
Coil approx. 2" dia. x 1" long

10 Transformers

1:1 ratio
115 VAC 60 Hz
1/2 kVA

10 Series Motor

28 VAC/DC
1/100 HP
7000 RPM
Approx. 2-1/2" dia. x 3" long
*AC volts*
Ranges: (Rms): 0 - 1, 3, 10, 30, 100, 300 and 1000 full scale
Ranges: (peak to peak) 0 - 2.8, 8.4, 28, 84, 280, 840 and 2800 full scale, frequency compensated
Input resistance: 10 megohms shunted by 29 pf
Frequency response: 10 Hz to 10 MHz
Accuracy: ±5% full scale
*Ohmmeter*

Ranges: 0 - 100 microamps, 1 mA, 10 mA, 100 mA & 1 ampere
Accuracy: ±3% full scale.
*General*
Meter: 4-1/2", 100 microamp ±2%, diode protected and isolated from input
Ohms battery: 1.5V "C" cell
Power supply battery: 9 volts

10 AC Milliammeter

0 - 1/2A
Mounted in meter case suitable for bench top use

10 Wattmeter

0 - 20 watts
Mounted in meter case suitable for bench top use
Dynamometer type

10 DC Current Meter Movement
44 ohm internal resistance
2-1/2" face

10 Variable transformer

0 - 130-volt output
115V 60 Hz input
2 amp fused

10 Student Tool Kit including:

Tool box
Soldering iron 35W
Diagonal cutters 6"
Long nose pliers 6"
Combination pliers 6"
Screwdriver 1/8" blade 2" shaft
Screwdriver 1/4" blade 4" shaft
Phillips screwdriver 3/16" blade, 3" shaft
Tweezers
Nutdriver set
12" rule
1" micrometer caliper

10 PM Motor

27.5 VDC
1/100 HP
15000 RPM
Approx. 2-1/2" dia. x 3" long

10 Solid State Regulated Low Voltage Power Supply

*Output*
0.5 - 50 VDC 1.5 amps
*Load regulation*
±15 millivolts
*Line regulation*
0.05%
*Ripple and noise*

Less than 150 microvolts
*Overload protection*
Current limiter and relay
*Metered*
*Dimensions*
5-1/8" x 13-1/4" x 9"

10 AC Motor

115 VAC 60 Hz
1/25 HP
3000 RPM
Approx. 2-1/2" dia. x 3" long

10 Workbench

*Top*
28-1/2" x 64" laminated maple 2-1/4" thick
*Legs*
31" high steel leg frames with steel stringer
*Wiring*
60" plug strip with 6 115-volt outlets prewired

20 Stools

*Construction*
Steel frame swivel type with back rest
Adjustable seat 22" to 27" high

1 Magnetic Chalkboard

4 x 8 feet with roll around stand

1 Demonstration Sliderule

Approximately 12" x 72" suitable for wall mounting

4 Storage Cabinets

18 gauge steel construction
Double doors with lock
3 adjustable shelves
36" x 18" x 78" outside dimensions

467 871 (OC 1366)